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# ALTERNATIVE FUELS FOR MARINE PROPULSION

## COMPRESSED NATURAL GAS

prepared by

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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

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17. Abstract

This project examined the feasibility of using compressed natural gas (CNG) in a dual fuel mode to power ferries on the east and west coasts of Canada. CN Marine and B.C. Ferry Corporation provided information on their vessel and routes. Preliminary calculations were made of CNG system requirements for three ferries with one-way trips of about one-half hour, 2½ hours and 5 hours, respectively. These calculations indicated that CNG systems would be feasible for short or medium trip lengths on the west coast. Annual savings would repay capital costs in three to six years. The cost of storage cylinders rules out CNG for long trips. On the east coast, the uncertainty of future natural gas prices in relation to the future cost of heavy oil/diesel fuel mixtures ruled against CNG as a proven future fuel for that market. A preliminary design was prepared for a specific B.C. Ferry vessel proposing a tractor-trailer system to carry CNG cylinders to a suitably designed compartment on the ferry.

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17. Résumé

Cette recherche étudie la possibilité d'utiliser le gaz naturel compressé GNC comme l'un des deux combustibles d'un système bimode de propulsion pour les traversiers opérant sur les côtes Est et Ouest du Canada. A partir des renseignements fournis par CN Marine et par B.C. Ferry Corporation sur les caractéristiques des traversiers qu'elles exploitent et sur leur itinéraires, des calculs préliminaires ont été faits concernant trois cas précis correspondant à des traversées simples d'une demi-heure, de deux heures et demi et de cinq heures environ, respectivement. Ces calculs ont montré qu'un système bimode est exploitable dans le cas des trajets courts et moyens sur la côte Ouest; les économies réalisables rembourseraient le capital investi entre trois et six ans. Le système bimode ne convient pas aux longs trajets, en raison du coût des bouteilles de GNC. Dans le cas de la côte Est, l'incertitude entourant les prix futurs du gaz naturel, comparativement à ceux des combustibles lourds ou diesel, a milité contre l'utilisation du GNC dans cette application. Par ailleurs, une étude préliminaire a été faite relativement à un traversier de B.C. Ferry; elle propose d'amener les récipients de GNC dans un compartiment spécialement aménagé, au moyen d'ensemble routier.

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## SUMMARY

This study was carried out for the Transportation Development Centre to evaluate the feasibility of using compressed natural gas (CNG) for ferries on the East and West coasts of Canada. The possibility of using CNG for this purpose was suggested by CN Marine who have an interest in assessing available alternative fuels for use in vessels which will be acquired in the future. Natural gas is an abundant indigenous fuel available at approximately half the cost of diesel fuel, and the use of CNG, if feasible, would have benefits to Canada in reducing dependency on foreign fuel supplies.

The project:

- reviews the background from a literature survey, from discussions with operators of an Australian CNG-powered vessel and by examining manufacturers' equipment lists and regulations
- analyzes the performance of ferry systems on both coasts to consider the likely candidates for CNG and to select three specific routes for evaluation
- considers the fuelling options for delivering CNG as a fuel to each of three specific routes for evaluation
- analyses the trade-offs, dependent on how frequently the refuelling is done and what method is used to transfer it
- prepares a preliminary design for one route which appears to have a pay-back period of less than three years through converting to CNG.

It suggests that consideration be given to monitoring a proposed implementation on the route for which the preliminary design has been prepared and contributing towards the learning costs in converting the first demonstration vessel.

## General Background

A review of the literature, manufacturers' equipment lists and regulations shows that:

- natural gas has been used in dual-fuel stationary diesel engines for over forty years and marine diesel engines for LNG vessels for over fifteen years
- compressed natural gas has been in satisfactory operation in a marine diesel engine in a limestone carrier - Accolade II - for two years
- compressed natural gas has been used successfully as a land vehicle fuel for fifty years and its installation in vehicles is supported by Federal and British Columbia government grants
- standard CNG equipment can supply the marine ferry applications identified, with the exception of fuelling hoses or connectors to transfer large volumes during a short turn-round period. Such transfers were not economic in the instances considered here but might be desirable for some applications
- there are no regulations specifically for CNG marine application and it will be necessary to design a system incorporating the relevant safety procedures developed in other applications, supplemented by special considerations of the marine environment vs land, or CNG marine vs LNG marine.

## The Ferry Systems

The principal relevant ferries of CN Marine on the East Coast are:

- St. John to Digby
- Prince Edward Island
- North Sydney to Port-aux-Basques

The other ferries either serve Newfoundland coastal communities, where there is unlikely to be natural gas for many years, or they serve Argentia and Bar Harbor with a relatively long journey and a relatively small annual fuel consumption, where the annual savings are unlikely to be large enough to justify the capital costs (unless liquid fuel costs rise dramatically or the fuel becomes unavailable).

The principal relevant ferries of B.C. Ferries on the West Coast are:

- Horseshoe Bay to Langdale (Sunshine Coast)
- Horseshoe Bay to Nanaimo (Vancouver Island)
- Tsawwassen to Swartz Bay (Victoria)

The Prince Rupert ferry journey is almost certainly too long to be served economically by CNG and the other ferries are short and will likely not justify conversion, although when new ferries or new engines are being considered, they could well be candidates.

## The CNG Fuelling Options

CNG can be transferred from dock to vessel:

- during the turn-round at the end of every round trip
- with a day's supply during the overnight layover
- with a day's supply during a special period during the day.

The transfer can be made by a hose from a compressor (with or without dock storage) or may be made by mobile means, e.g. by driving on a trailer of natural gas cylinders.

## Analysis of Trade-offs

For the East and West Coast ferry systems, the most economic systems require the transfer of gas every round-trip. There is no ferry route where all the vessels serving it layover at night where there is a supply of natural gas. Moreover, even if the schedules were changed to permit such loading, the number of on-board cylinders for a day's supply is high, costly and (if steel cylinders are used) heavy.

When a special period is set aside during the day for transferring a day's supply, the high volume of gas has to be transferred in a short time, implying a high volume of expensive dock storage to push the volume through the hose connectors.

Mobile transfer of natural gas by driving on a trailer appears the most economic system for a route served by a single vessel. Where a system of several ferries uses a common facility, then a compressor with dock storage serving fixed ship storage in the multiple vessels may be warranted, since the dock storage cost is shared amongst the several vessels.

## Preliminary Design

The prime candidate for an initial system is the Langdale ferry with a low estimate capital cost of $1.3 million, including the cost of engine conversion, and has a pay-back period of between two and three years.

The preliminary design indicates a compressor located about 8 km from the ferry terminal where natural gas is available at 500 kPa (75 psig). Three standard trailers are proposed, each holding 2 000 cu.m (70 000 SCF) of gas. Normally one will be on the ferry, one at the compressor and one in transit or waiting.

A special fuel compartment to store the trailer is located on the vessel where it does not hinder vehicle traffic and where it can be vented directly to atmosphere.

Once in the compartment, the trailer is coupled to a high pressure gas line which leads directly to the engine room. Here two high pressure regulators lower the pressure and final low pressure regulators control the ultimate pressure of supply into the engine.

Safety systems are proposed to:

- release the gas to atmosphere in the event of a fire threatening the integrity of the high pressure cylinders
- shut off the gas in the event of a break at the trailer caused by a collision or other means
- shut off natural gas supply in the event of a line break, a gas leak or an electricity failure.

## Engine Conversion

For dual-fuel use, the amount of work required to satisfactorily convert a specific large diesel engine cannot be predicted with certainty. The Accolade II reported lower power on CNG but this is not necessarily true with all conversions, when other engine and turbocharger adjustments have been made. M.A.K., who make the major engines used by B.C. Ferries, are reviewing the problem in converting their engines and have not indicated that they foresee any major hurdles. Estimated costs of conversion have been based on a conversion of a similar large diesel of Hawker Siddeley.

## Conclusions

CNG appears economic for the Langdale, Nanaimo and Victoria routes of B.C. Ferries and for the Digby route of CN Marine. It is recommended that monitoring of engine maintenance costs on CNG, diesel and blended fuels be carried out, since additional savings through lower maintenance and greater reliability coupled with lower than now-estimated engine conversion costs may make the Prince Edward Island and Port-aux-Basques routes economic. These improved data may be available by the time any conversion for these routes has to be planned.

The benefits to Canada are for the saving of 45 to 65 million litres of liquid fuel a year and a halving of fuel bills of $15 to $20 million a year by changing to CNG.

## Recommendations

It is recommended that the Federal Government consider cooperating with the B.C. Ferries intended plan to convert the Langdale ferry to CNG as a demonstration. Such cooperation could include the provision of monitoring services to record engine and vessel performance before and after conversion, or funding assistance for first-time learning costs particular to this installation which could have a wider Canadian application.

## CONTENTS


| | | Page |
|---|---|---|
| 1.0 | INTRODUCTION | 1 |
| | 1.1 Objective | 1 |
| | 1.2 Report Structure | 1 |
| | 1.3 Units of Measurement | 2 |
| 2.0 | BACKGROUND INFORMATION | 3 |
| | 2.1 Literature Review | 3 |
| | 2.2 Potential Competitor Fuels to DFD | 4 |
| | 2.3 The Accolade II | 5 |
| | 2.4 Equipment Available for High-Volume CNG Use | 5 |
| | 2.5 Related Regulations | 8 |
| 3.0 | FERRY SYSTEMS | 11 |
| | 3.1 System Routes | 11 |
| | 3.2 Routes for Evaluation | 15 |
| 4.0 | ANALYSIS OF FUEL SUPPLY OPTIONS | 17 |
| | 4.1 Refuelling Frequency and Methods | 17 |
| | 4.2 Rates of Gas Compression and Transfer | 19 |
| | 4.3 Capital Costs of the Various Options | 21 |
| | 4.4 Saving in Fuel Costs | 25 |
| 5.0 | PRELIMINARY DESIGN AND COSTS FOR THE LANGDALE FERRY | 27 |
| | 5.1 Compressor Installation | 27 |
| | 5.2 Trailer and Truck Configuration and Logistics | 30 |
| | 5.3 The Fuel Compartment on the Vessel | 30 |
| | 5.4 Connections and Piping | 33 |
| | 5.5 Pressure Regulators | 33 |
| | 5.6 Engine Conversion and Controls | 35 |
| | 5.7 Safety System | 38 |
| | 5.8 Costs | 40 |
| 6.0 | CONCLUSIONS | 41 |
| APPENDIX A: | Technical Data on the Ferry Vessels | |
| APPENDIX B: | Fuel Energy Equivalents | |

## 1.0 INTRODUCTION

This introduction presents the objective of the Transportation Development Centre in sponsoring the study. It describes the outline of the report and discusses some of the units of equivalence between natural gas and diesel fuel for those not familiar with both fuels.

### 1.1 Objective

The Transportation Development Centre (TDC) of Transport Canada is examining the use of alternative fuels for Canadian marine propulsion applications.

In its review of the subject, TDC discovered that a significant amount of work on alternative fuels was already in progress worldwide and concluded that Canadian research into alternative fuels for marine propulsion should be directed towards those specific Canadian marine operations that would benefit from readily available alternative fuels proven to have advantages from both economic and long-term supply considerations.

Alternative fuels meeting these criteria are compressed natural gas (CNG), propane, and liquefied natural gas (LNG). However, propane and LNG present additional safety problems. Moreover, the technology exists for the use of CNG as a fuel for marine diesel engines. This gas is clean burning and non-polluting. It has been used in a dual-fuel marine system with diesel fuel being used for high power, quick response maneuvering, and CNG being used for steady state sailing.

Therefore, it was decided that the study should evaluate the specific use of CNG as an alternative marine fuel in an appropriate application and explore the various technologies, both existing and near-future, involving the storage, transfer and use of CNG on shipboard and at dockside.

Following review and discussions with CN Marine and B.C. Ferries, the ferry system was selected by TDC as a suitable application for an in-depth feasibility study of the use of CNG as a marine fuel.

The scope of this study covers the investigation of the economic and logistic considerations in using CNG as a fuel, and includes a review of the cost and availability of existing equipment for CNG storage and transfer for marine use, with consideration given to regulatory and safety aspects.

### 1.2 Report Structure

The report is presented in five further sections:

- Background
  - a literature review, a review of liquid fuels used, a review of the Accolade II, a survey of equipment for high-volume CNG use, and a consideration of related regulations.
- Ferry systems
  - an overview analysis of ferry routes, fuel consumption and performance, and a selection of potential candidate routes.

- Analysis of fuel supply options
  - an evaluation of the frequency of refuelling, the method of refuelling, and an analysis of trade-offs to be made.

- Preliminary design and costs
  - a preliminary design for a selected route and its estimated costs.

- Conclusions and recommendations

The first four sections are summaries of material presented in Working Papers 1 to 4 respectively. The last section draws together the basic analyses and presents conclusions and recommendations.

## 1.3 Units of Measurement

For those readers who are not familiar with measurements of volumes of natural gas, a simple rule of thumb is that a litre of diesel fuel is about equivalent to 1 cu.m of natural gas at atmospheric pressure and $21^{0}C$ ($70^{0}F$). Gas quantities when expressed in cu.m refer to the volume the gas would occupy at a pressure of 1 atmosphere. When gas is compressed at 16 500 kPa (2 400 psig) or 160 atmospheres, it takes up approximately 1/200th of the space it occupies at 1 atmosphere, i.e. it requires 5 litres of volume rather than 1 000 litres (=1 cu.m). Thus compressed, natural gas at this pressure requires about five times the volume of the equivalent amount of diesel fuel.

The basic metric measure of energy used in this report is the gigajoule (GJ), as used by B.C. Hydro for example in billing its customers. One gigajoule is the energy contained in 25.9 litres of #2 diesel or 26.9 cu.m of natural gas at atmospheric pressure and $21^{0}C$.

Cost figures in the report are in 1983 Canadian dollars unless otherwise stated.

## 2.0 BACKGROUND INFORMATION

This section reports on:

- a review of the literature
- potential competitor fuels to diesel
- the Accolade II
- equipment available for high volume CNG use
- related regulations.

### 2.1 Literature Review

A computer literature search was conducted to determine relevant information on the use of natural gas to fuel large diesel engines (greater than 1100 KW-1500 HP) intended for marine applications.

The data bases included in this search were:

- NTIS (National Technical Information Service) Data Base, 1964-83.
- Engineering Index - Data Base, 1970-83.
- Canadian Transportation Documentation System - Data Base, 1960-83.
- Society of Automotive Engineers - Data Base, 1965-83.
- Information Service in Mechanical Engineering Data Base, 1973-83.
- OOT (Transport Canada Library) - 1971-81.
- Abstracts of the Journal of the British Ship Research Association - 1975-82.
- TRIS (Transportation Research Information Service) - 1968-83.
- OON (Canada Institute for Scientific and Technical Information) - 1978-83.

The key words used to obtain appropriate information from the data bases were:

- natural gas and diesel
- natural gas and marine
- dual fuel and diesel
- dual fuel and marine

The computer search provided over 500 references with the NTIS search accounting for the majority of the References. The majority of the references were found to relate to the powering of tankers from LNG "boil-off".

The following are the key findings of the literature review.

Natural gas, unlike diesel fuel, will not normally ignite from compression alone in a diesel engine. There are two methods currently used to ignite natural gas in a diesel engine:

pilot-ignition, in which a small quantity of diesel fuel (typically 5% to 30%) is injected in addition to the natural gas, so that the diesel fuel ignites due to compression. This type of system can also be used with 100% diesel, as well as in the pilot-fuel mode

spark-ignition, in which a spark plug is added to the diesel engine to ignite the natural gaseous mixture. This type of engine operates on 100% natural gas and cannot normally be operated on diesel fuel.

Natural gas has been used as a fuel for stationary four stroke diesel engines for more than forty years. The applications for these engines is typically to operate compressors and pumps. Both spark-ignition and pilot-fuel systems are used.

Marine applications of natural gas to power vessels has only recently occurred. During the 1960's a number of liquefied natural gas ocean transports were constructed. Those used the "boil-off" from the LNG storage tanks to fuel dual-fired steam boilers. The ships so fuelled (Methane Progress, Methane Princess and Jules Verne) have operated with a high degree of reliability, although the thermal efficiency of their power units are considerably lower than that for a diesel cycle. Because of this a number of diesel engine manufacturers (Sulzer and M.A.N.) have developed dual-fuel (i.e. methane/diesel) conversion systems for their large marine diesel engines. The former engines are two stroke while the latter are four stroke engines. The conversion systems for these engines have been very successful.

When very small amounts of diesel fuel (about 5%) are used, there is typically a reported power loss for the engine of 15%. However, when approximately 30% diesel fuel is used no power loss is experienced. There is however, not enough evidence to be sure that this will be true for any specific engine, even if the trend exists. Sulzer has found a number of important advantages to operating their engines in a dual-fuel mode including:

- reduced pollution through the use of higher grade fuel;
- reduced cylinder and piston wear;
- lower temperature levels in the combustion chamber;
- lower piston temperatures;
- lower lubricating oil costs;
- lower liquid fuel injection pressure.

In summary, the above factors all contribute to marked reduction in maintenance costs and increase in engine life for a marine diesel power plant. This, together with reduced fuel costs, provided a strong incentive for the use of the dual-fuel engines for marine applications. As a result, a number of LNG carriers are currently operating successfully with dual-fuel diesel engines using the boil-off from the LNG tanks.

## 2.2 Potential Competitor Fuels To Diesel

CN Marine has converted some of its vessels to operate on a blend of 60% heavy-fuel/40% diesel, and is anticipating that new vessels will be designed to operate on a 90% heavy-fuel/10% diesel blend. It is acknowledged that these blended fuels lead to higher maintenance.

Some operators, such as the Canadian Navy and BC Ferries, have evaluated heavy fuels and have determined that for the type of engines they have, the price they would have to pay for heavy fuel and the maintenance costs they anticipate, such blends are not appropriate.

BC Ferries has also reviewed the potential of coal or CNG, since both are abundant indigenous fuels, offering security of supply, and producing positive spin-off benefits to the provincial economy.

## 2.3 The Accolade II

The Accolade II is a limestone carrier owned and operated by Adelaide Brighton Cement Co. Ltd. and has an overall length of 108.63 m, breadth of 23 m beam, a draft of 6 m and a deadweight of 7 500 tonnes. The vessel travels a round trip of 152 km (82 nautical miles) each day and is refuelled overnight. It is propelled by two Fuji 6LG32X dual-fuel engines, each of 1 340 kW downrated to 1 230 kW (1 650 HP). Each engine is turbo-charged at 150 kPa (23 psig).

The dockside system consists of a 37 kW (50 HP) Ingersoll Rand 3-stage compressor. The inlet pressure is from 790 to 1 140 kPa (120 to 170 psig) and the compressor can deliver from 14 to 22 cu.m/min (500 to 775 cfm), depending on the inlet pressure. Overnight it is connected to the ship fuel system by a flexible bunkering hose of 25 mm diameter.

The fuel system on the vessel stores approximately 6 200 cu.m of natural gas (equivalent in energy to about 6 000 litres of diesel fuel) in 21 steel cylinders, each 9 m high by 0.52 m in diameter, at a pressure of 16 500 kPa (2 400 psig).

In Canadian currency equivalent, the ship cost an additional $750 000 for on-board equipment, and a further $120 000 was required for dockside equipment.

In 1981, natural gas in Adelaide cost about $2.50 per GJ compared with about $10.00 per GJ for diesel fuel. An 80/20 CNG/diesel fuel utilization therefore costs $4.00 per GJ, saving $6.00 in comparison with 100% diesel fuel. The ship consumes about 170 GJ per day for 300 days a year, saving over $300 000 per year. This repays the additional capital costs in under three years. Moreover, there have been maintenance savings, although there is no estimate of their dollar magnitude yet.

(This cost of natural gas is under 60% of the cost of firm natural gas for Canadian application or under 75% of the cost of interruptible gas, so the economics are more attractive in Australia than they would be for this application in Canada).

## 2.4 Equipment Available for High-Volume CNG Use

Since a ferry requires the use of high volumes of CNG with the possibility of a requirement to transfer these high volumes in relatively short periods, a review was made of the availability of off-the-shelf equipment for that purpose. The review covered:

- Compressors
- Equipment for tranferring compressed gas
- Storage containers
- High pressure regulators.

## Compressors

Compressors are used in gas pipeline systems as well as at CNG fuelling stations and are available in a range of sizes. A price list was obtained from J-Mar Compressors, a B.C. firm, and a list of equipment was also obtained from Atlas Copco. CNG Fuels Ltd. manufactures compressors in Canada. These costs show that compressors of the size of 10 cu.m/min (350 cfm) are standard. RIX compresors Inc. of California also manufacture units of 14 cu.m/min (500 cfm). Since there are advantages in having compressing capacity provided by several units so that one may be down for maintenance, these units will be adequate for most marine purposes. If it were desired to have a compressor to serve a system of many ferries operating from a single port, then a larger compressor would be required but this could be specially ordered from one of the major manufacturers.

## Equipment for Tranferring Natural Gas

Three types of transfer system may be considered for supplying natural gas to ferries. In one, the compressors will supply the ship directly by overnight slow-fill as is done with the Accolade II. In a second, the compressor will supply dock storage, from which natural gas will be transferred by fast-fill to the vessel during its turn-round time at the dock. In the third, natural gas cylinders will be filled on a trailer and driven on to the ferry.

For overnight slow-fill, the Accolade II uses a 25 mm hose. Such a hose can deliver about 30 cu.m/min . One or two hoses of this diameter, or if necessary somewhat larger, will be adequate for most such purposes and are readily available.

For fast-fill during turn-round, it is possible that special equipment will have to be developed. As long as the volume is within the capability of a small number of standard flexible hoses, then the equipment is available. However, for some of the longer marine ferry runs with round trips of almost 12 hours, the volumes of gas to be transferred through a hose or pipe in 30 minutes would be beyond the capability of existing hoses. A special connection would have to be designed. At some point, the limiting factor might, in theory, be the cylinder neck and the ability to pass gas through there, although this is not anticipated as a real problem.

For transfer by a trailer, a number of standard units are available; FIBA-Canning leases or sells such units. A smaller trailer holds about 2 000 cu.m (70 000 SCF) and the largest 5 700 cu.m (200 000 SCF). These trailers are licensed to operate by the Canadian Transport Commission. Their 16 500 KPa (2 400 psig) cylinders are approved and such units operate now over highways in Canada. They may, for example, be towed to a building where there is no piped natural gas supply and be coupled to provide space heating. Without the wheels, such units filled with natural gas are being carried regularly as cargo on marine vessels.

## Storage Containers

Three types of storage containers may be considered for both dock storage (if any) and for storage on the vessel. These are:

ASME containers
CTC/DOT containers
lightweight composite containers

ASME (American Society of Mechanical Engineers) containers are pressure vessels which meet a prescribed ASME code and are manufactured by an approved supplier. They are designed to be installed permanently in a place where people work or congregate. The Accolade II stores its natural gas in such containers and they would appear appropriate for a permanent installation in a ship. Their major problem will be weight. A container 6.7 m long X 0.5 m diameter holds 312 cu.m (11 000 SCF) of gas and weighs 1.50 tonnes. The gas in such a container weighs 0.222 tonnes (compared with 0.264 tonnes of equivalent diesel).

Natural gas plus its container therefore weighs 6.5 times as much as the equivalent amount of diesel fuel. Larger ASME vessels are available but a weight penalty is likely to be at least 6 times that of diesel fuel.

## CTC/DOT Containers

Containers approved by the Canadian Transport Commission or the Department of Transportation in the United States are intended for the mobile transfer of various gases. In most Provinces and States, these containers are also approved for ground storage of CNG at refuelling stations, sometimes by the expedient of mounting them in wheeled wire basket containers to maintain a legal fiction that they are mobile. However, the containers have to be inspected every five years and this makes their use inconvenient when they are permanently secured in a relatively inaccessible location, as would likely happen in a ship. Unless they can be located in an easily accessible position on the ship or are transported on by mobile means, they are not likely to be suitable for on-board storage. They would however, be quite suitable for on-dock storage use and are accepted for this purpose by the appropriate Provincial regulations on the West and East Coast at this time.

## Composite Containers

Light weight containers of composite materials reduce the weight problem and such containers are available and have been given an exemption from the steel specification requirements by the U.S. Department of Transportation (and accepted by the Canadian Transport Commission). However, containers of the size required for use in ferries (rather than an automobile) have not been manufactured for commercial sale, although B.C. Hydro in a feasibility study, identified a California supplier who indicated that he would be able to supply a size comparable to the ASME containers quoted above at a cost about equal to that of ASME containers. We have no assurance that this supplier would be able to follow through with a firm quotation and delivery date in accordance with his indications, but it would clearly be worth pursuing as an option where larger permanent on-board containers are to be used.

### High Pressure Regulators

High pressure regulators are available in a range of sizes and at least one supplier - Fisher - produces a regulator capable of supplying 31 cu.m/min (1 100 cfm). Since it is possible to use more than one regulator, this should be adequately large for any foreseen use.

## 2.5 Related Regulations

There are no specific regulations for CNG vessels or for shore-based refuelling stations. However, there are regulatory agencies who will have to be satisfied that any proposed system is safe. These agencies will be:

- Canadian Coastguard
- Lloyd's Registry
- Provincial Boiler and Pressure Vessel Inspectors.

Initial contact has been made with the Coastguard Service. They confirm that they would review a specific proposal on its merits. They would review LNG regulations that might be appropriate for CNG also (e.g. for venting requirements), based on the Code for the Construction and Equipment of Ships Carrying Liquefied Natural Gases in Bulk, produced by the International Marine Consultative organization in London. The coastguard are reluctant to consider a passenger ferry for a first application because CNG is a novel fuel in marine use and they would prefer a first application to a non-passenger vessel.

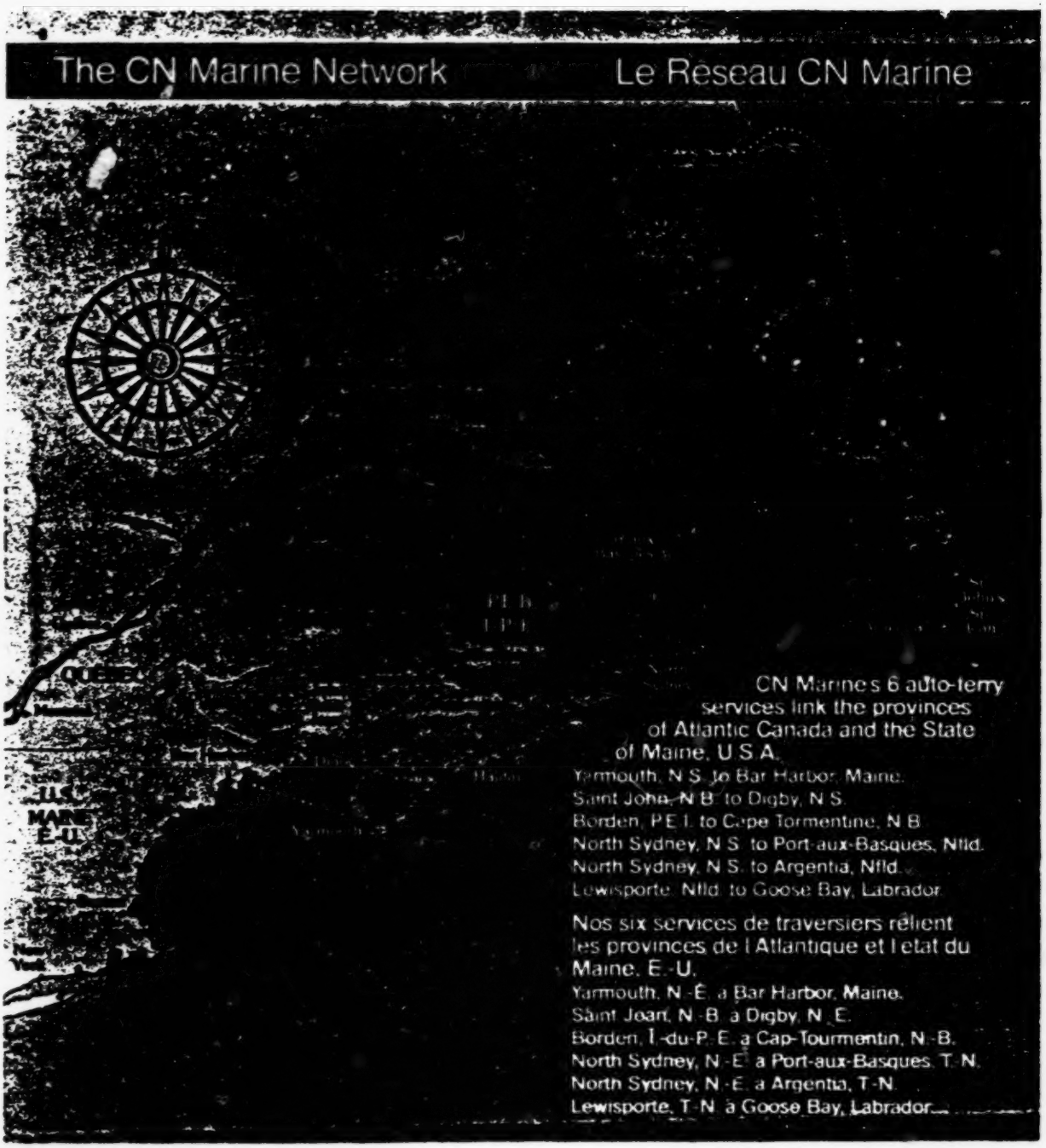
Initial contact has also been made with Lloyd's Registry. The relevant section of their register is Part 1, Chapter 2 of Rules and Regulations for Classification of Ships. The fact that the Accolade II has a Lloyd's certificate will be of assistance. It may be noted that Lloyd's regulations for LNG vessels limit pressure of gas on board the vessel, require a hood over each engine, and require all piping to be contained within an outer jacket vented to atmosphere. Given the high pressure cylinders on a CNG-powered ship, and the design of the specific turbo-charged diesel engines used in the ferries, some of these regulations may not be appropriate. Moreover, with the provision of more extensive safety systems, such as automatic shut-off valves operated by gas detectors and flow-break detectors, it may be safer to leave the piping exposed to reveal and find any leak as early as possible. The existing regulations for LNG are therefore a useful guide, but any CNG system needs to be designed to be safe for its particular use. This will require similar but not necessarily identical regulations.

Refuelling stations for highway vehicles are covered by Amendment #1 to CAN1-B149.1-M80 - Installation Code for Natural Gas Burning Appliances and Equipment. This standard does not apply to refuelling stations for marine vessels but the Pressure Vessel Inspectors would review the requirements of that Code for guidance on safety measures that should be enforced. Factors such as valves, safety relief devices, approved components and equipment would be similar for systems serving automobiles and marine vessels.

However, given the wide differences in quantities and rates of fuel to be delivered, standards for fuel delivery hoses and connections should be expected to be different for the different applications. There would also be no necessary requirement to retain the Canadian Standard pressure for automobile systems of 3000 psig (20 680 kPa).

A National Fire Protection Association standard (NFPA 52) defines requirements for CNG refuelling and storage inside buildings, which can also act as a guide to similar safety measures for CNG storage and piping on board a ship.

Exhibit 1
East Coast Routes


The CN Marine Network
Le Reseau CN Marine
CN Marine's 6 auto-ferry services link the provinces of Atlantic Canada and the State of Maine, U.S.A.
Yarmouth, N.S. to Bar Harbor, Maine.
Saint John, N.B. to Digby, N.S.
Borden, P.E.I. to Cape Tormentine, N.B.
North Sydney, N.S. to Port-aux-Basques, Nfld.
North Sydney, N.S. to Argentia, Nfld.
Lewisporte, Nfld. to Goose Bay, Labrador.
Nos six services de traversiers relient les provinces de l'Atlantique et l'etat du Maine, E.-U.
Yarmouth, N.-É. a Bar Harbor, Maine.
Saint Jean, N.-B. a Digby, N.-E.
Borden, Î.-du-P.-E. a Cap-Tourmentin, N.-B.
North Sydney, N.-É. a Port-aux-Basques, T.-N.
North Sydney, N.-É. a Argentia, T.-N.
Lewisporte, T.-N. a Goose Bay, Labrador.

## 3.0 FERRY SYSTEMS

This section describes the ferry routes generally and identifies three routes which span the range of conditions where CNG may be applicable. The purpose of selecting three routes has been to provide a base for which to examine the impact on costs of such factors as different frequencies of refuelling and different methods of transferring natural gas.

### 3.1 System Routes

Exhibit 1 shows a map of CN Marine's East Coast systems and Exhibit 2 a map of the B.C. Ferry System on the West Coast. These systems are described below and the estimates of engine fuel consumption on the major routes are presented. Technical data on the vessels are presented in Appendix A.

#### EAST COAST SYSTEM

The East Coast system has seven routes as follows:

- Prince Edward Island (Cape Tormentine to Borden)
- Port aux Basques (North Sydney to Port aux Basques)
- Argentia (North Sydney to Argentia)
- Digby (St. John to Digby)
- Bar Harbor (Yarmouth to Bar Harbor)
- Labrador (Lewisporte to Goose Bay)
- Newfoundland Coastal (various coastal routes)

#### Prince Edward Island

Prince Edward Island is served on a year-round basis by the Abegweit, which carries rail cars, trucks and passengers. This is supplemented in the summer months by the Vacationland and the Holiday Island, which are passenger and vehicle ferries designed to handle the tourist traffic. Another large ferry may supplement the Abegweit if necessary.

The one-way journey takes about 42 minutes in the summer peaks, with an 18 minute turn-round, allowing the two smaller vessels to maintain an hourly schedule at peak times. Off peak, the journey time is lengthened to save fuel and the turn-round time is also correspondingly longer.

#### Port Aux Basques/Argentia

The Gulf routes to Newfoundland are served by the Frederick Carter, Nordica Atlantica, and Ambrose Shea supplemented by other vessels as necessary.

With the growth in container traffic, the Frederick Carter, one of the largest rail-car ferries in the world, will shortly be obsolete and must be replaced by a large roll-on, roll-off freighter. This vessel will be designed for one round trip a day from North Sidney to Port-aux-Basques each day of the year.

The fleet will be rationalized with the advent of the M.V. Caribou in 1985, which is designed for one trip a day from North Sidney to Port-aux-Basques in the winter and two trips a day in the summer.

Further rationalization of the passenger vessels may take place, in which case the leases of the Marine Nautica and Atlantica will not be renewed.

The trip to Port aux Basques takes six hours and is regarded as the basic service to Newfoundland, although it requires passengers for St. Johns to make a long overland journey on arrival in Newfoundland. The Argentia service, with an 18 hour journey, is offered as a convenience three times a week in the summer to take passengers close to the centre of population in Newfoundland.

Digby

The St. John to Digby route is served by the Princess of Acadia, which during the summer season maintains a continuous shuttle through the 24-hour period. The vessel makes six one-way trips a day, with a scheduled sailing time of 2.5 hours and an average scheduled turn round time of 1.5 hours (range of 1.25 to 2.0 hours).

The vessel is equipped with a marine version of a locomotive engine which burns diesel fuel and is not convertible to heavy fuel.

Bar Harbor

The Yarmouth to Bar Harbor route is served in the summer by a daily round trip of 6 hours duration in each direction. At other times, the ferry normally operates a 3 days a week schedule. The terminal at the U.S. end is located in a National Park.

Labrador

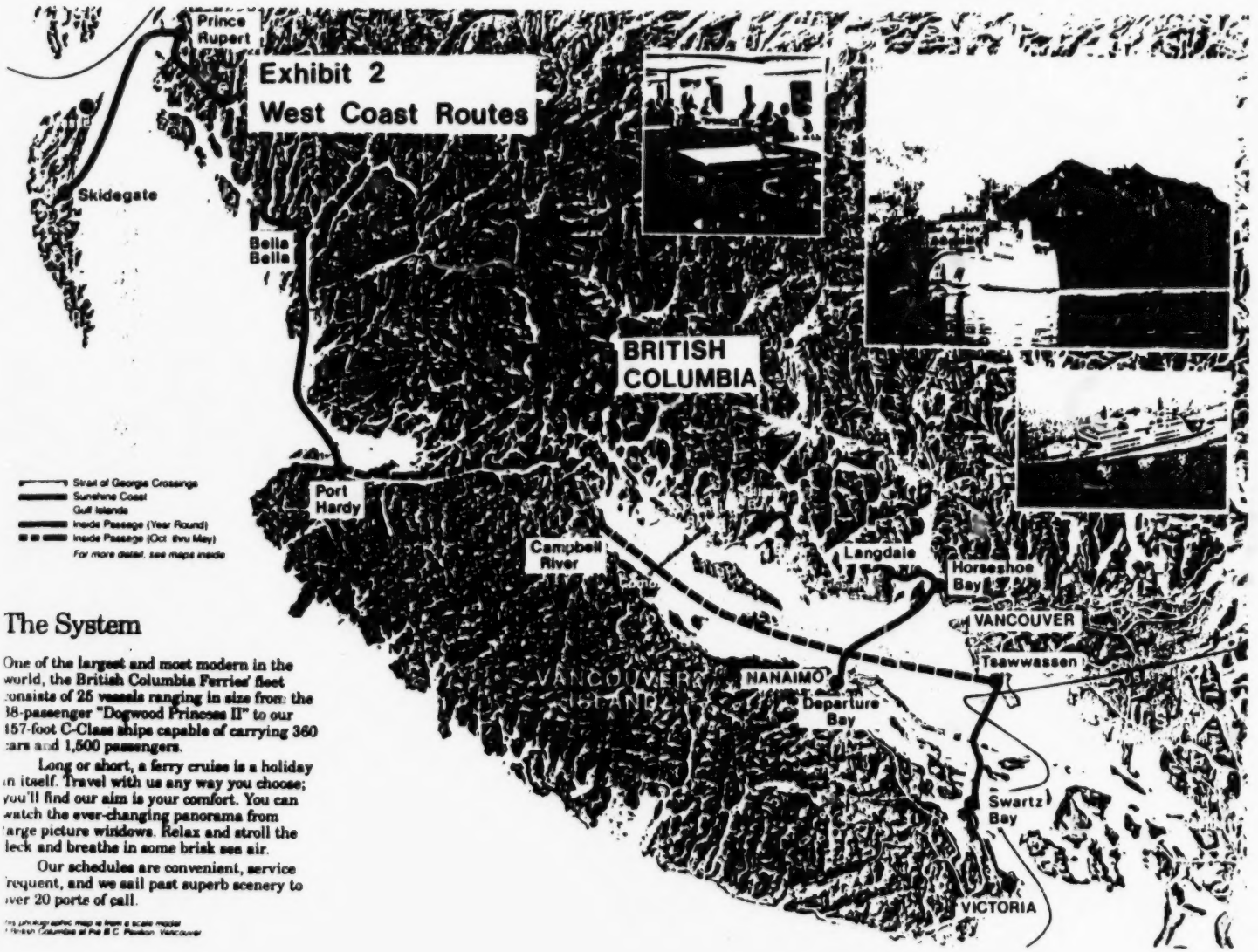
A vessel leaves Lewisporte, Newfoundland twice a week in the summer months to serve Cartwright and Goose Bay. The sailing time is approximately 32 hours.

Newfoundland Coastal

A series of routes serves the Newfoundland coastal communities from Port aux Basques to Burgeo, Francois and Terrenceville; the intervening communities between Lewisporte and Goose Bay; and Goose Bay to Nain. The schedule shows 515 round trips in the year 1983 with an average one-way distance of 200 nautical miles between the start and the finish.

**WEST COAST SYSTEM**

The West Coast System has four major routes and a number of smaller routes primarily serving small island or coastal communities. These are:




## The System

One of the largest and most modern in the world, the British Columbia Ferries' fleet consists of 25 vessels ranging in size from the 38-passenger "Dogwood Princess II" to our 457-foot C-Class ships capable of carrying 360 cars and 1,500 passengers.

Long or short, a ferry cruise is a holiday in itself. Travel with us any way you choose; you'll find our aim is your comfort. You can watch the ever-changing panorama from large picture windows. Relax and stroll the deck and breathe in some brisk sea air.

Our schedules are convenient, service frequent, and we sail past superb scenery to over 20 ports of call.

This photographic map is from a scale model of British Columbia at the B.C. Pavilion, Vancouver

- Victoria (Tsawwassen to Swartz Bay)
- Nanaimo (Horseshoe Bay to Departure Bay)
- Langdale (Horseshoe Bay to Langdale)
- Prince Rupert (Port Hardy or Vancouver to Prince Rupert)
- Other Services

Victoria

The Vancouver to Victoria route is provided with hourly service in the summer from 7am to 9pm, using four ferries with a one-way sailing time of approximately 1 hour 35 minutes and a turn-round time of 25 minutes. In the winter, two ferries provide service every two hours; in the shoulder season three ferries are used. A typical vessel serving this route would be the Queen of Burnaby (see Appendix A) or a similar vessel of this class.

Nanaimo

Vancouver to Nanaimo is similarly provided with hourly service in the summer from 7am to 9pm, using larger ferries to travel the larger distance to Nanaimo (compared with Victoria) in approximately the same time. Winter and shoulder season schedules are similarly reduced from the summer peak. A typical vessel serving this route would the be the Queen of Coquitlam (see Appendix A) or a similar vessel of this class.

Langdale

The Sunshine Coast is served by a Vancouver to Langdale route, in which one vessel provides 10 trips daily in each direction in the summer peak, with a journey time of approximately 35 minutes. It is planned that this route be served by the Queen of Alberni (see Appendix A).

Prince Rupert

Prince Rupert is served in the summer by ferries (Queen of the North and the Queen of Prince Rupert - Appendix A) which provide daily service from Port Hardy (on Vancouver Island), with a 16 hour trip and an 8 hour stop over. About once a week, a stop is made in Ocean Falls. In the winter once a week service is provided from Port Hardy and once a week service from Vancouver (29.5 hour trip).

**Other Services**

A number of smaller ferry services operate between island and coastal communities:

- Vancouver, Victoria and the Gulf Islands
- Saltspring Island and Vancouver Island
- Vancouver and Bowen Island
- Earls Cove and Saltery Bay (two coastal communities)
- Prince Rupert and the Queen Charlotte Islands

These are substantially smaller vessels than the mainline services, providing basic transportation for residents, although there is of course a significantly increased summer Island population creating a seasonal demand for these services also.

Only Vancouver and Prince Rupert terminals are likely to have natural gas available within the near future.

Engine Fuel Consumptions on Major Routes

Exhibit 3 shows the number of trips a year made on each of the routes described above, the length of the routes and the estimated engine fuel consumed on each. Where data are not available, engine fuel consumption has been estimated as being 80% of the total fuel consumption of the vessel. The balance is used for electric generation and heating.

CN Marine generally uses a 60/40 mix of heavy fuel and diesel at a cost of about 27¢ per litre, resulting in an annual bill for engine fuel of about $15 million. An exception is the Princess of Acadia on the St. John/Digby route which uses diesel fuel only, at a cost of about 31¢ per litre.

B.C. Ferries uses diesel fuel at a cost of about 31¢ per litre, resulting in an annual engine fuel bill of about $20 million.

The above prices are based on actual 1983 fuel costs of the two systems.

## 3.2 Routes for Evaluation

From the above routes, three have been selected to evaluate the effect on costs of different frequencies of refuelling and different methods of transferring natural gas. The three selected routes are:

Horseshoe Bay to Langdale
St. John to Digby
North Sydney to Port-aux-Basques

Each of the routes has (or potentially will have) natural gas available now (West Coast) or by approximately 1990 (East Coast) at one end of its route. The vessels burn at least 1 500 litres an hour and fuel cost savings would be substantial. The lengths of runs are 35 minutes, 2 1/2 hours and 5 1/2 hours respectively. Two of the routes are served by vessels which would be converted to dual-fuel operation and one (to Port-aux-Basques) may be served by a new vessel constructed for CNG utilization. We assume this new vessel will be a large freighter, replacing the Carter, and consuming 2,500 litres of fuel an hour (equal to that of the present Carter). It will operate one round trip a day, year round.

## EXHIBIT 3

### ROUTE INFORMATION

| | Scheduled One-way Trips/Yr.* | One-way Hours | Sailing Hours/yr. | Engine Litres/ Hour | Millions of Litres/Year Engine Fuel | Peak # Of Vessels |
|---|---|---|---|---|---|---|
| PEI - Small Vessels | 6294 | 0.7 | 4400 | 1000 | 4.4 | 2 |
| - Large Vessels | 3334 | 0.5 | 1670 | 2400 | 4.0 | 2 |
| PORT AUX BASQUES | 1752 | 6.0 | 10500 | 1600 | 16.8 | 3 |
| ARGENTIA | 180 | 18.0 | 3240 | 1600 | 5.2 | 1 |
| ST.JOHN/ DIGBY | 1400 | 2.5 | 3500 | 1590 | 5.6 | 1 |
| YARMOUTH/ BAR HARBOUR | 394 | 6.0 | 2360 | 1440 | 3.4 | 1 |
| LABRADOR | 52 | 32.0 | 1660 | 1000 | 1.7 | 1 |
| NEWFOUNDLAND COASTAL | 1030 | 12.6 (AV) | 13000 | 700 | 9.1 | 4 |
| VICTORIA | 7992 | 1.6 | 12970 | 1520 | 19.7 | 4 |
| NANAIMO | 7278 | 1.8 | 13100 | 1850 | 24.2 | 4 |
| LANGDALE | 6126 | 0.7 | 4120 | 1750 | 7.2 | 1 |
| PRINCE RUPERT (Summer)<br>(Winter) | 178<br>70<br>70 | 16.0)<br>16.0)<br>29.5) | 5800 | )1400<br>)<br>) | 8.1 | 2 |
| OTHER (Gulf Island, Bowen, Saltspring Island) | - | - | - | - | 5.0 (approx) | |

* A trip with multiple stops, (e.g. Lavisporte, Newfoundland to Goose Bay, Labrador) is counted as a single one-way trip and measured from its start to finish.

## 4.0 ANALYSIS OF FUEL SUPPLY OPTIONS

There are a number of options for supplying the selected routes with CNG. The basic choices to be made are:

- The frequency of refuelling
  - should it be every trip, slow-fill overnight or fast-fill with a day's supply?

- The method of refuelling
  - should it be by hose from dock storage or by mobile storage on a trailer driven on to the ferry?

In the sections below, the operational factors affecting the choice of refueiling frequency and method are discussed. The rates at which gas has to be compressed and transferred are then calculated for each route by relating the volume required to the time available for the compression or transfer. These times vary with the refuelling frequency and method selected.

The sizes of compressors, fuel storages and other system requirements are then calculated and costed. The capital costs are compared with operating cost savings to compute the years to pay back the investment.

### 4.1 Refuelling Frequency and Methods

The major options for frequency of refuelling are:

- every round trip
- during an overnight layover
- during a special lay-over pe.iod.

The advantage of refuelling every round-trip is that on-board storage is held to a minimum at the expense of requiring the transfer of a high volume of gas in a short period of time. (It may be noted that refuelling every one-way trip is not possible since no ferry has natural gas available at both ends of its run, except the winter-only Vancouver-Prince Rupert service).

The major alternative is to refuel with a day's supply, this being most simply done during an overnight layover. However some ferries do not have an overnight layover, maintaining a 24-hour operation for at least six days a week in the peak period. Other ferries layover at a location which does not have a supply of natural gas; for routes served by more than one vessel, half the ferries always overnight where there is no gas. It may therefore, be necessary to arrange an extended turn-around time of perhaps two to three hours during which a day's supply can be transferred.

The major options for method of refuelling are:

- by hose from a compressor or from dock storage
- by mobile means.

## EXHIBIT 4

## COMPRESSION, STORAGE AND DELIVERY RATES REQUIRED FOR CNG

| | Propulsion Liquid Fuel per Round Trip (litres) | Cu.m of Natural Gas† | | Hours Between Sailings | | Minutes of Turn Round at Dock | Cu.m/min. To Supply If Done: | | | Cu.m/min. to Supply During Turn Round |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Per Round Trip | Per Peak Day | During Day | Overnight | | Average Over 24 hrs | Between Sailings | Overnight | |
| LANGDALE | 2350 | 1850 | 18500 | 1.83 | 5.0 | 20 | 12.8 | 16.8 | 61.7 | 92.5 |
| DIGBY | 7940 | 6260 | 18780 | 8.00 | * | 75 | 13.0 | * | * | 83.5 |
| NEW CARTER | 30000 | 23650 | 23650 | 24.00 | 11.0 | 660 | 16.4 | 16.4 | 35.8 | 35.8 |

† At standard temperature and atmospheric pressure.

* No overnight layover in summer.

Note: The liquid fuel is assumed to contain 38.5 MJ/litre - see Appendix 1.
Natural Gas is assumed to contain 39.1 MJ/cu.m - see Appendix 1.
Engines are assumed to use 80% CNG:20% Diesel in CNG operation.

The hose appears the simplest method but when only a short period is available to transfer gas, it requires large amounts of dock storage to be available to push the necessary volume through in the time available.

Mobile transfer avoids this problem but it is not so easy to find an unused part of the ship into which to arrange the transfer. The simplest concept for mobile transfer is a standard trailer driven on, and this has been assumed in later analyses.

## 4.2 Rates of Gas Compression and Transfer

The amounts of natural gas required for each ferry on the three selected routes have been computed assuming that 80% of the liquid fuel used for propulsion (as distinct from electric generation or heating) will be replaced by CNG. The balance of diesel will be required for initial and final maneuvering and as a pilot fuel when running. The rates at which gas will require to be compressed and transferred have then been calculated based on the time available for these operations. The results are shown in Exhibit 4. The basis of computing the natural gas equivalent of #2 Marine Diesel is presented in Appendix B.

The amount of on-board storage will be essentially equal to the cu.m of natural gas required, i.e. if refuelled every trip, it will be one round-trip's supply; and if refuelled daily, it will be a peak day's supply.

The amount of dock storage will be related to the amount of on-board storage and the time available for transfer of fuel. With a long period of transfer, e.g. 6 hours or more, two cu.m of dock storage are required for every one of ship storage. When dock storage of 2 units is connected by a hose to the empty ship storage, the system eventually reaches equilibrium with 1 unit in dock storage and 1 unit in ship storage. When only a short time is available however, more dock storage is required. Computer simulation indicates that 3 cu.m of dock storage may be required for every cu.m of ship storage if the transfer time is of the order of two hours. When the transfer time is about 1/2 hour, 4 cu.m of dock storage may be necessary for every cu.m of ship storage.

Compressor size will essentially be equal to the cu.m/min to be supplied, with an allowance added for spare capacity, e.g. to provide for shut-down for maintenance. In preparing a preliminary design it has been assumed that a spare capacity of 10% will be planned for the operational compressor units and, in addition, allowance will be made for one-third of the capacity to be down for maintenance or to provide an operational break. This is a conservative assumption. As an example, the Langdale route consumes fuel at an average rate of 16.8 cu.m/min during sailing hours (i.e. excluding the layover at night). This analysis plans for 10% higher than this, i.e. 18.5 cu.m/min, and then provides three units of at least 9.3 cu.m/m, in capacity so that any two can supply the load at any one time.

Hose size (or interconnection size) is indicated by the last column in Exhibit 4. Since a standard hose can supply about 30 cu.m/min, the Langdale, Digby and New Carter present no problem. However, there would be a problem in attempting to fuel a vessel with its daily supply in a short

## EXHIBIT 5

### System Sizes

| | Compressor Capacity* cu.m/min | Dock Storage cu.m | Ship Storage cu.m |
|---|---|---|---|
| **LANGDALE** | | | |
| Trip Refuelling | 27.7 | 7 400 | 1 850 |
| Mobile Refuelling | 27.7 | 3 700 | 1 850 |
| Mid-day Refuelling | 27.7 | 55 500 | 18 500 |
| Overnight (8 hours) | 63.6 | 0 | 18 500 |
| **DIGBY** | | | |
| Trip Refuelling | 21.5 | 25 040 | 6 260 |
| Mobile Refuelling | 21.5 | 6 260 | 6 260 |
| Mid-day Refuelling | 21.5 | 56 340 | 18 780 |
| **NEW CARTER** | | | |
| Trip Refuelling | 27.1 | 47 300 | 23 650 |
| Mobile Refuelling | 27.1 | 23 650 | 23 650 |
| Overnight | 59.1 | 0 | 23 650 |

*Including spare capacity of 10%, plus one spare unit for each two operational ones.

period. The Gulfspan from North Sidney to Port-aux-Basques in its summer use, for example, would require to be supplied with approximately 70,000 cu.m of gas during its half hour stopover. This would require the design of a special connector, perhaps of the order of 10 cm in diameter.

## 4.3 Capital Costs of the Various Options

The performance data above are used to determine key measures of system size. These are then used to estimate system capital costs.

### System Size

Exhibit 5 shows the size of compressor, on-board storage and dock storage for each of the options which appear practical methods of refuelling each of the three systems.

"Trip Refuelling" denotes the refilling of the ferry from fixed dock storage at the end of each round trip. Dock storage for the Langdale and Digby ferries is assumed to be 4 cu.m for each 1 cu.m of ship storage to enable the gas to be transferred in the time available. For the New Carter, eleven hours is available and dock storage of 2 cu.m for each cu.m of ship storage will be adequate.

"Mobile Refuelling" denotes the transfer of natural gas cylinders by trailers at the end of each round trip. For the Langdale route, three trailers are assumed (one on the ship, one at the dock and one at the compressor) since the compressor is located off-dock to obtain higher pressure gas. For the other locations, the compressor is assumed to be at the dock.

"Mid-day Refuelling" denotes loading a day's supply during a two-to-three hour turn-round. Dock storage is taken as 3 cu.m for each 1 cu.m of ship storage. Mid-day refuelling is not an option for the New Carter since it only makes one trip a day and then overnights for eleven hours.

"Overnight" denotes slow-fill overnight by compressor with no dock storage. The Langdale ferry overnights at Langdale and the crew live in that community, but since there is no natural gas in Langdale, overnight refuelling would have to be carried out at Horseshoe Bay. For the purposes of calculation in this report, it has been assumed that the schedule and crewing procedures would be changed to permit overnighting at Horseshoe Bay. However, if this option turns out to be attractive, the management would have to evaluate the significant costs in changing the crew location and in providing an overnight capability at Horseshoe Bay.

Eight hours is assumed to be available for overnight refuelling at Langdale. However, on peak summer days only five hours may be available. On these days the vessel would have to use more diesel fuel. Overnight is not an option for the Digby ferry which provides continuous 24-hour service on summer weekdays.

## EXHIBIT 6

## Estimated Capital Costs of CNG Conversion ($000s)

| | Compressor Units, Housing & Controls | Dock Storage | Ship Storage | Fuel Compartment, Piping Safety Systems | Fuel System Total | Engineering and Contingencies | Engine Conversion | Total Cost |
|---|---|---|---|---|---|---|---|---|
| **LANGDALE** | | | | | | | | |
| Trip Refuelling | 800 | 300 | 90 | 150 | 1 340 | 340 | 500 | 2 180 |
| Mobile Refuelling | 470 | * | * | 150 | 620 | 150 | 500 | 1 270 |
| Mid-day Refuelling | 800 | 2 200 | 890 | 200 | 4 110 | 1 030 | 500 | 5 640 |
| Overnight (8 hours) | 1 840 | 0 | 890 | 200 | 2 930 | 730 | 500 | 4 160 |
| **DIGBY** | | | | | | | | |
| Trip Refuelling | 470 | 1 000 | 300 | 150 | 1 920 | 480 | 600 | 3 000 |
| Mobile Refuelling | 470 | * | * | 150 | 620 | 150 | 600 | 1 370 |
| Mid-day Refuelling | 470 | 2 250 | 900 | 200 | 3 820 | 950 | 600 | 5 370 |
| **NEW CARTER** | | | | | | | | |
| Trip Refuelling | 460 | 1 890 | 1 140 | 200 | 3 690 | 920 | 0 | 4 610 |
| Mobile Refuelling | 460 | * | * | 200 | 660 | 170 | 0 | 830 |
| Overnight | 920 | 0 | 1 140 | 200 | 2 260 | 570 | 0 | 2 830 |

* Leased and included in fuel costs.

## System Costs

These system sizes are converted into costs in Exhibit 6. Three-stage compressor unis are costed at $14 300 for each cu.m/min of capacity to be installed, based on the price per cu.m estimated for the Langdale preliminary design. The Langdale ferry will however, require a four-stage compressor if mobile refuelling is not used, because only 100 kPa (15 psig) gas is available at the dock. This increases costs to $29 000 for each cu.m/min, assuming compressors are chosen with no more than 750 RPM, so as to keep maintenance costs down and maintain operating reliability. In addition, $70 000 has been added for housings for the units, heaters, controls and electricity supply. Digby has been assigned the same size system as Langdale (although it is apparently smaller) because the ferry schedule is not uniform and the system needs a greater peaking ability.

Dock storage is costed at $40 per cu.m assuming CTC cylinders will be used and ship storage $48 per cu.m, based on ASME cylinders (or lightweight cylinders at equal cost, if available). These cylinders permit storage at a pressure of 24 800 kPa (3 600 psig). For mobile refuelling, trailers of cylinders have been assumed to be leased. Standard units, as commmercially available, consist of a number of large tubes containing natural gas at a pressure of 16 500 kPa (2 400 psig).

Providing a fuel compartment on the vessel for fixed or mobile storage, connecting it by piping to pressure regulators in the engine room, and providing a safety system was estimated at $150 000 in the Langdale ferry preliminary design. An additional $50 000 has been added where a full day's supply has to be stored to allow for the larger and more complex system required.

Engineering and contingencies of the fuel system has been estimated as 25%, being approximately 10% for engineering and 15% for contingencies.

Engine conversion has been assumed to be $400 000 for the first engine in each vessel, based on a cost quoted by Hawker-Siddeley to B.C. Hydro as having been required to convert a comparable engine. The costs were said to represent 75% materials and 25% labour, indicating major structural changes to the engine. Based on initial discussions with MAK representatives, such changes are not anticipated for their engines. However, to allow for the learning costs, the conversion of a first engine has been accepted at $400 000. The cost for the second engine has then been assumed to be $100 000 and for subsequent engines $50 000. Since the Langdale ferry has two engines and the Digby ferry has four, this basis of costing leads to engine conversion cost estimates of $500 000 and $600 000 respectively. The New Carter would be built initially with a dual-fuel engine.

It is difficult to know how much confidence to place in the conversion cost estimate since the bulk of it represents a learning cost, not a hardware cost. Given the potential market for large dual-fuel engines, it could be argued that the manufacturer should incur the learning cost and amortize it over all converted engines not just the first one. This may in fact occur. However, for the purpose of this analysis, the full estimated conversion cost has been included.

## EXHIBIT 7

### Annual Costs and Savings - $000s

| | Trips per Year | GJ per Average Trip | Gas Cost (including Compressor Operation) | Equipment Leases & Manpower | Total Gas Cost | Liquid Fuel Cost | Annual Savings |
|---|---|---|---|---|---|---|---|
| **LANGDALE** | | | | | | | |
| Trip Refuelling | 2 850 | 91 | 1 330 | 0 | 1 330 | 2 090 | 760 |
| Mobile Refuelling | 2 850 | 91 | 1 330 | 230 | 1 560 | 2 090 | 530 |
| Mid-day Refuelling | 2 850 | 91 | 1 330 | 0 | 1 330 | 2 090 | 760 |
| Overnight (8 hours) | 2 750 | 91 | 1 280 | 0 | 1 280 | 2 010 | 730 |
| **DIGBY** | | | | | | | |
| Trip Refuelling | 650 | 306 | 1 110 | 0 | 1 110 | 1 600 | 490 |
| Mobile Refuelling | 650 | 306 | 1 110 | 110 | 1 220 | 1 600 | 380 |
| Mid-day Refuelling | 650 | 306 | 1 110 | 0 | 1 110 | 1 600 | 500 |
| **NEW CARTER** | | | | | | | |
| Trip Refuelling | 340 | 1 155 | 2 190 | 0 | 2 190 | 2 160 | (30) |
| Mobile Refuelling | 340 | 1 155 | 2 190 | 310 | 2 500 | 2 160 | (340) |
| Overnight | 340 | 1 155 | 2 190 | 0 | 2 190 | 2 160 | (30) |

## 4.4 Saving in Fuel Costs

For the purposes of this analysis it has been assumed that natural gas will be purchased on an interruptible basis. Such gas costs about 80% as much as firm gas. The relative prices of firm gas and diesel oil are such that it would only make sense to buy firm gas if interruptions were to cut off interruptible supplies for over 60 to 70 days a year. BC Hydro recommends planning for interruptions of 30 days on average, although experience of the last four years has only led to 5 to 10 days of interruptions. The coldest year on record (1969) led to interruptions of less than 60 days. The 30 day figure has been used in the calculations below as a conservative basis of estimation.

Fuel prices (per GJ) have been computed as:

| | | |
|---|---|---|
| Diesel (both Coasts) | | 8.04 |
| 80% Interruptible Gas/20% Diesel | (West Coast) | 4.26 |
| | (East Coast) | 4.64 |
| Blended Fuel for the New Carter | | 5.51 |

Operating and maintenance cost of the compressors, based on B.C. Hydro experience, is taken as 20% of the cost of natural gas supply.

In addition, for mobile refuelling, a tractor and trailers have to be leased. For Langdale, costs have been added for a third trailer and a fulltime driver position to allow for the travel to an off-dock compressor location. Labour cost to fill the tractor driver position at Langdale for 14 shifts a week has been taken as $150 000 per year. At the other locations, no additional trailer or labour are asssumed.

Rental costs have been taken as:

| | |
|---|---|
| Tractor (including fuel and maintenance) | $40 000 per year |
| Each Trailer | |
| - 2 000 cu.m | $14 400 per year |
| - 7 000 cu.m | $36 000 per year |

Exhibit 7 shows the estimated annual costs of supply by natural gas and by liquid fuel. The number of trips a year is an estimate of those for which natural gas will be able to be supplied. This assumes a loss due to non-availability of interruptible gas and, if overnight refuelling is done, some summer weekends for the Langdale ferry when a full eight hours is not available.

By comparing Exhibits 6 and 7, the Langdale ferry installation is estimated to repay its capital costs in 2.4 years with mobile refuelling. It would repay the higher capital costs of trip refuelling (using a four-stage compressor, dock storage and fixed cylinders in the ships) in 2.9 years. Other systems at Langdale take 5 to 7 years to repay their costs.

The Digby Ferry, using mobile refuelling, is estimated to repay its capital costs in 3.6 years. Trip refuelling, based on dock storage and fixed on-board cylinders, requires 6.1 years.

The New Carter is more expensive using natural gas than using its planned blended fuel, if no allowance is made for the reduced maintenance costs using CNG. These benefits would have to amount to $620 000 a year for the annual savings to repay capital costs of the most economic system in three years. Since the maintenance savings are judged unlikely to exceed $50-100 000 per year, the economics are not attractive for a vessel using a blended fuel consisting of 90% heavy fuel unless the management places a premium on low maintenance and/or security of supply.

On the basis of the costs assumed in this report, natural gas and a 90/10 heavy fuel blend are about equal in cost on the East Coast, and the capital cost of compressors and storage containers cannot be justified on the basis of fuel savings alone for any route served by a newly constructed ferry. However, East Coast natural gas costs have not yet been established and this conclusion could change when more certain price estimates are available.

## 5.0 PRELIMINARY DESIGN AND COSTS FOR THE LANGDALE FERRY

Based on the above analysis, the consultant in consultation with the Project Steering Committee, concluded that a preliminary design should be prepared for the Queen of Alberni, serving the route from Horseshoe to Langdale in British Columbia. This system had the shortest pay-back period and a relatively low capital cost. If implemented, it could readily be expanded to the more extensive Nanaimo system and then to the Victoria system.

This section outlines the general nature of the system proposed and then describes each of the system components. It presents estimates of costs based on suppliers' price lists and verbal quotations and on our present understanding of the amount and scope of work to be done and the safety requirements to be met. No guarantee is made of their accuracy for final design purposes.

The proposed system is one in which a trailer of cylinders is filled at an off-dock site by a compressor. The trailer is towed by a tractor to the ferry terminal and is interchanged with a corresponding empty trailer when the ferry has docked and all passengers and vehicles have disembarked. The empty trailer is then towed to the compressor station for refilling. Exhibit 8 illustrates the system diagrammatically.

The sections below describe:

- the compressor installation
- the trailer and truck configurations and logistics
- the on-board storage compartment for the trailer
- connections and piping to the engine room
- the pressure regulators
- engine conversion and controls
- the on-board safety systems.

### 5.1 Compressor Installation

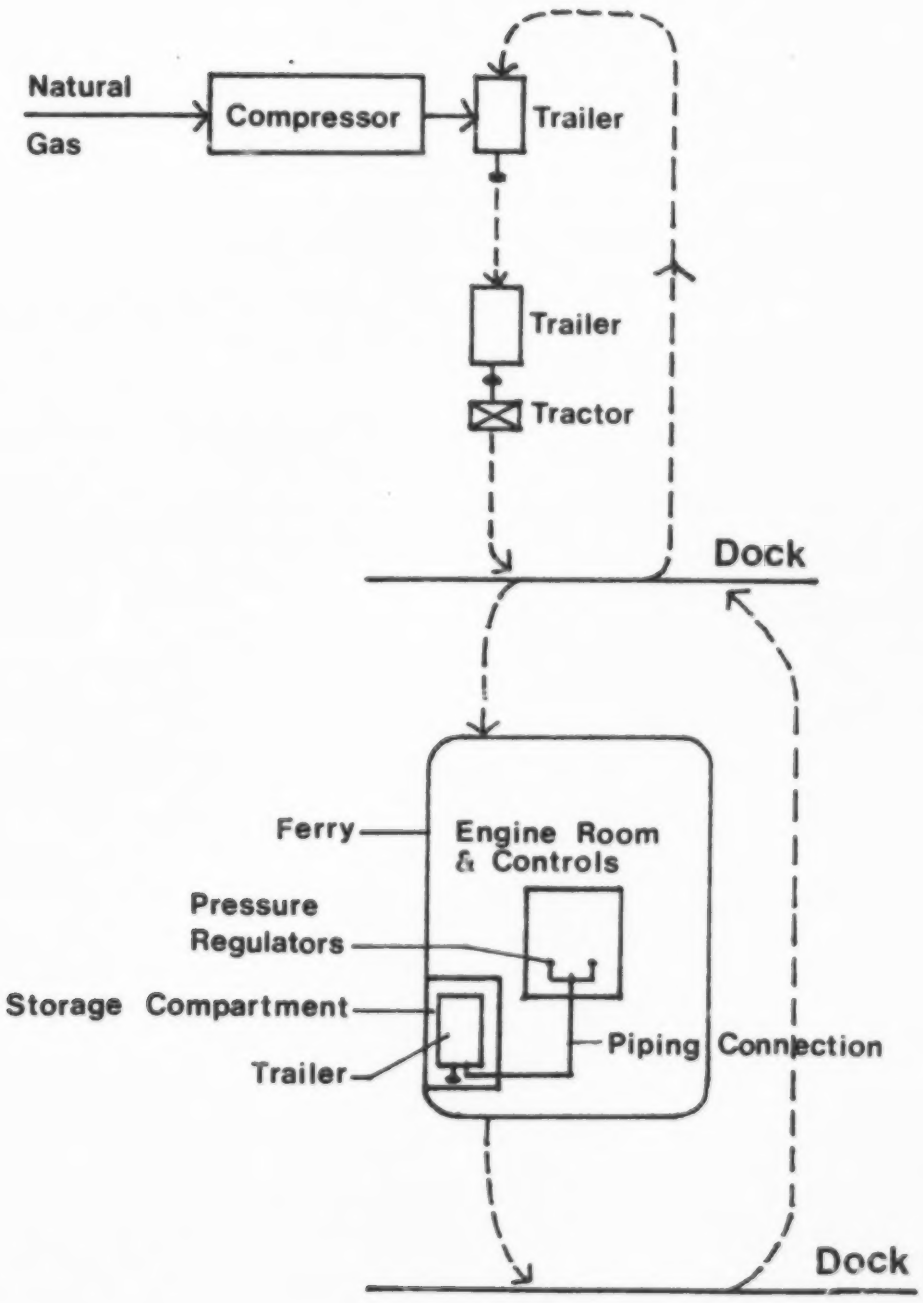
The compressor is required to supply 1 850 cu.m (65 300 SCF) of gas for every round trip of 110 minutes or 16.8 cu.m per minute (595 cfm). To provide for contingencies, as has been noted above, the design allows for 10% more than this and then provides one spare compressor unit for every two operational ones. The requirement under this philosophy is, for example, for three units of 9.25 cu.m per minute (325 cfm) each, any two of which will in combination have the capacity to supply 18.5 cu.m per minute (655 cfm). At the final design stage, when the choice is made of a specific manufacture and model of compressor, a more accurate judgment can be made of the appropriate amount of spare capacity to provide.

Sites are available:

- in the immediate neighbourhood of the Horseshoe Bay terminal with an inlet pressure of 100 kPa (15 psig)
- about 8 km away with an inlet pressure of 500 kPa (75 psig)
- about 20 km away with an inlet pressure of 1 000 kPa (150 psig).

# Exhibit 8

## System Description



With an inlet pressure as low as 100 kPa, a 4-stage compressor will be necessary. This is potentially noisy and a normal unit will have a relatively low delivery rate. While higher delivery rates are possible with high revolutions per minute, a responsible maintenance policy will propose that for a continuously operating compressor in heavy duty service, the maximum number of revolutions per minute be limited to about 750.

Using this limit, the nearest available compressors from one suppliers' price list are:

| Inlet Pressure (kPa) | Compressor Listed RPM | cu.m/min | Number Required Operational | Spare | Operating Capability cu.m/min | Capital Cost of Total Units |
|---|---|---|---|---|---|---|
| 100 | 600 | 4.11 | 4 | 2 | 16.4 | $649 000 |
| 500 | 750 | 9.77 | 2 | 1 | 19.5 | $316 000 |
| 1000 | 550 | 9.18 | 2 | 1 | 18.4 | $314 000 |

While the six compressors at 100 kPa inlet pressure (four of them operational at any one time) fall marginally short of the stated delivery requirements, the revolutions per minute could be increased (but to less than 750) and thus meet the demand. There would be almost no additional capital cost.

On the basis of a three year pay-back requirement, it would only be worth locating at Horseshoe Bay (with an inlet pressure of 100 kPa) and incurring the high compressor cost, if the marginal cost of travel for a driver and tractor were assessed at more than $2.50/km, which appears unreasonably high.

Another factor which might suggest incurring the higher cost at Horseshoe Bay would be long-term continuity should this installation be an initial one, soon to be expanded to the larger fleet serving Nanaimo.

It is felt that if such an expansion were to follow, then it would almost certainly justify the construction of a higher capacity line to Horseshoe Bay. A four-stage compressor would not then be necesary but greatly increased compressing capacity would be required, one component of which might be the original compressor transferred to the new filling location.

It therefore appears appropriate to seek a site about 8 km from the ferry terminal with an inlet pressure of approximately 500 kPa (75 psig).

At this site would be located the three compressor units, each in its own enclosure with a set of controls and a heater. The output from the three units would be manifolded and provided with two refuelling connectors (to provide a spare if one is unavailable). An electrical substation and a firm gravel refilling site will also be required. It is estimated that the costs of these items, including Federal and Provincial taxes will be:

| | |
|---|---|
| Compressor units | 400 000 |
| Enclosures, controls, etc. | 70 000 |

## 5.2 Trailer and Truck Configuration and Logistics

It is proposed that the system include three trailers, each with a capacity of 2 000 cu.m (70 000 SCF) of natural gas at 16 500 kPa (2 400 psig). Normally, one trailer will be on the ferry, one at the compressor and one in transit or waiting. A trailer of this kind is illustrated in Exhibit 10 (page 37).

Given the relatively short travel time between the ferry terminal and the compressor (about 15 minutes round trip), it will be possible to operate with only two trailers, provided the compressor station can refill the empty trailer in about 95 minutes rather than 110 minutes. This will be possible when the full compressor power is available, and the system thus permits a trailer to be taken out of service for maintenance or any other reason. Even if one compressor and one trailer were down simultaneously, it would just be possible to refill in 95 minutes, but then there is no cushion in the event of highway or other delays. The ferry in this situation would have to use a higher proportion of diesel fuel.

When the ferry arrives and all the vehicles have been taken off and the ship is empty of passengers, the tractor will go on board and remove the empty trailer from its compartment and tow it off. The full trailer will then be taken on board, placed in its compartment, have its wheels clamped and be connected to the ship's fuel system. The compartment door will then be locked and the tractor will leave.

Two possible locations have been identified on the Queen of Alberni. One is at the starboard side close to #1 end as shown in Exhibit 9. The other is on the port side close to #2 end*. If located at #1 end, as shown in Exhibit 9, the empty trailer would first be towed from the compartment and backed off the vessel; the full trailer would then be towed on to the vessel and backed into the compartment. If located at #2 end, the empty trailer would be towed straight off the vessel; the full trailer would be backed down the length of the vessel into the compartment.

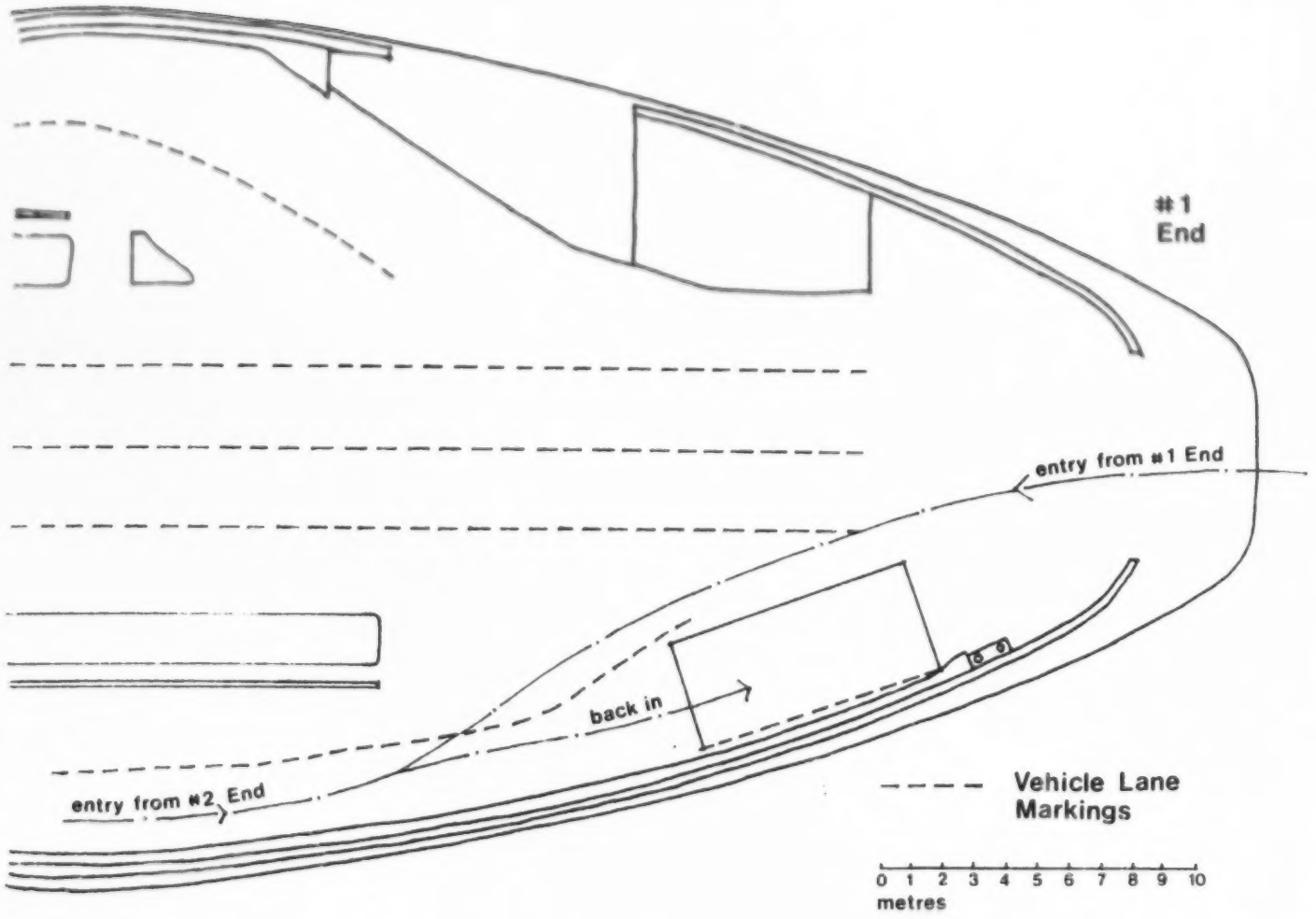
It is estimated that the trailers could be rented for $1 200/month each and a tractor for $40 000/year, including fuel and maintenance costs.

## 5.3 The Fuel Compartment on the Vessel

The compartment on the vessel has to hold a trailer which is 7.2 m (23'6") long x 2.4 m (8'0") wide x 2.6 m (8'6") high. It is proposed that the compartment be about 8 m x 3.5 m, solid on three sides (one of which would include a door) with the fourth side substantially open to the atmosphere. The lower portion of the outside may be protected with a barrier against salt spray from below. The roof would be sloping from a height of about 3.5 m (11'6") on the inner side to 5.0 m (16'6") on the outer side.

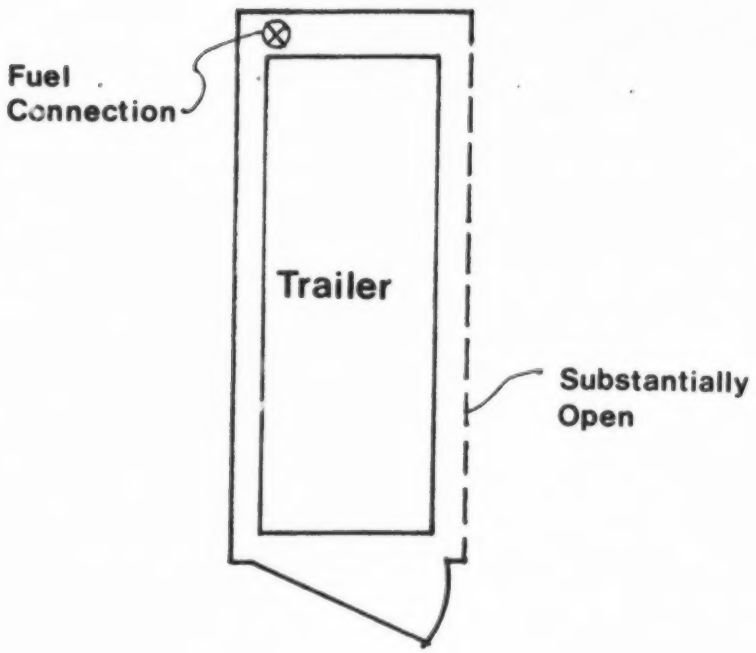
* The ferry is double ended, so the two ends are numbered for reference as #1 and #2. #1 is regarded as the bow and #2 as the stern. Conceptually therefore, the vessel travels forward from Langdale to Horseshoe Bay (with #1 end forward) and then back from Horseshoe Bay to Langdale (with #2 end forward).

## Exhibit 9
## Trailer Location on Ferry

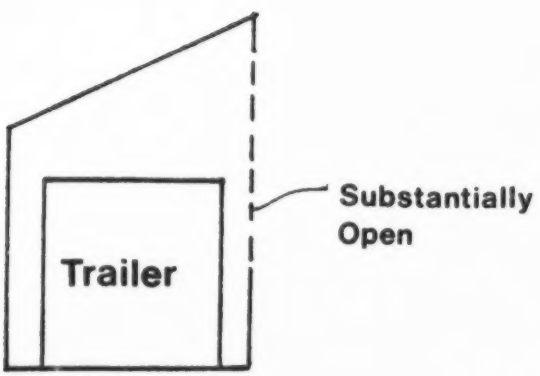


# Exhibit 11

## The Fuel Compartment




a) Plan View




b) Elevation

The above design ventilates the system completely to the atmosphere, while protecting it from vandalism. The sloping roof prevents pockets of gas from accumulating if leaks should develop or if, for example, a safety relief valve sould relieve in the event of a fire.

The compartment is shown schematically in Exhibit 11. It is estimated that its cost would be approximately $80 000.

## 5.4 Connections and Piping

The system from the compartment to the engine will consist of:

- a shut-off valve located at the outlet of the hose from the trailer
- a fuelling connection in the compartment
- approximately 60 m (200 ft) of piping from the fuelling connection to the engine room.

In the engine room, the piping will be connected to high pressure regulators as described in the next section.

The average rate of flow of natural gas for the Queen of Alberni is approximately 17 cu.m/min (600 cfm) rising to almost 30 cu.m/min (1 050 cfm) when the engine is running with natural gas at its highest rate. The piping system for the ferry must be able to transmit this quantity of gas under all conditions, including when the pressure in the fuel tanks is low. Allowing for the compressibility of natural gas at high pressure and assuming that the piping system has relatively smooth surfaces to minimize surface friction, the diameter of the piping system required has been found to be approximately 5 cm, with a reasonable safety factor built into this calculated value. The maximum flow velocity in the pipe will be considerably below sonic (typically less than 0.2 of sonic), since sonic velocities in constant diameter pipes can be maintained for only short distances.

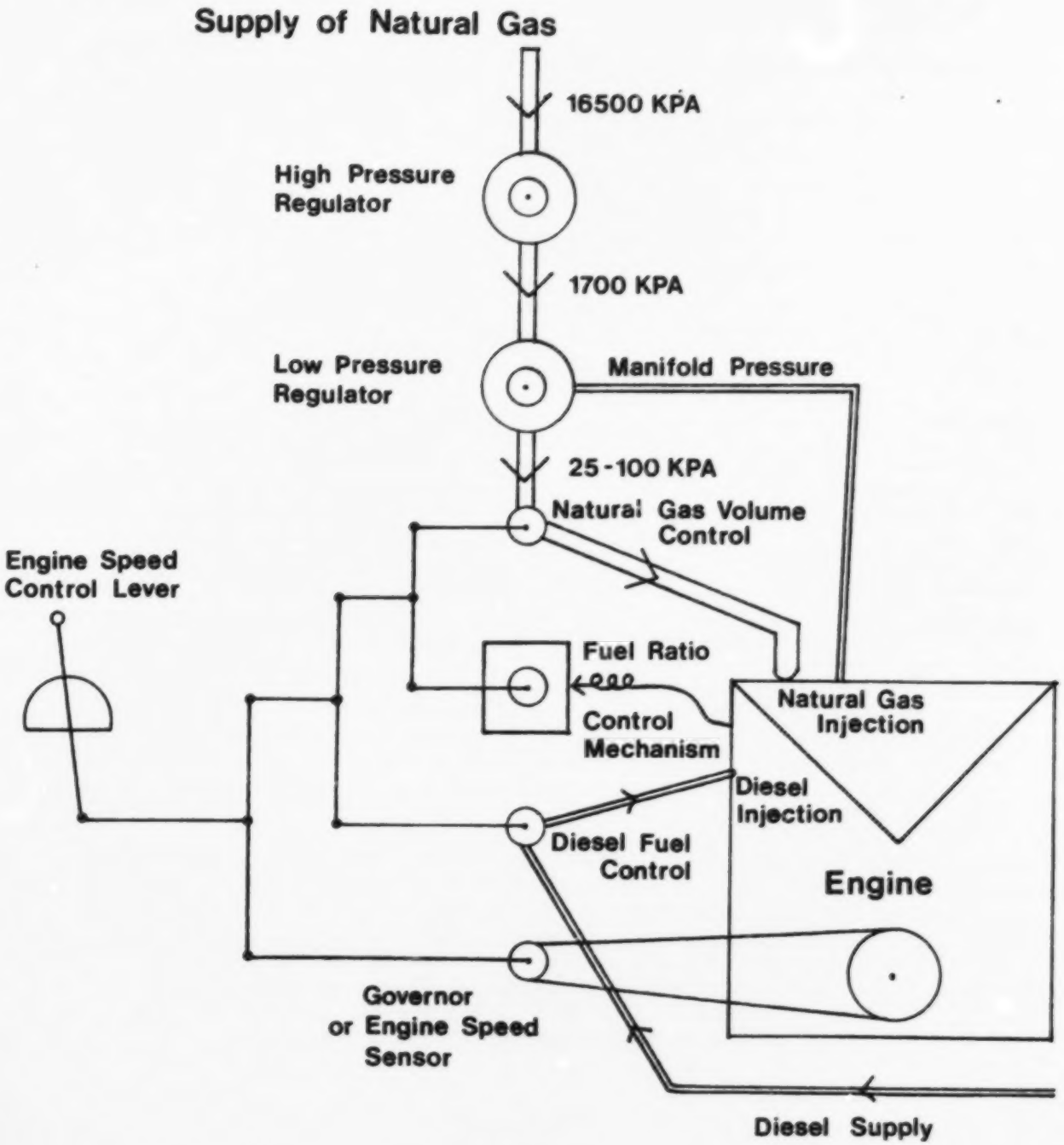
The pipe will be corrosion-resistant, capable of withstanding 16 500 kPa (2 400 psig) and assembled from 6 m (20 ft) sections, joined by connections and elbows approved for high pressure service. It will be supported about every 50 cm with brackets. It is estimated that the fuelling connection, piping and brackets will cost about $10 000 and may cost approximately $15 000 to install.

## 5.5 Pressure Regulators

Two high pressure regulators will be used to reduce the pressure from 16 500 kPa (2 400 psi) to 1 700 kPa (250 psi). They will draw on heated water from the engine to meet temperature requirements. Each high pressure regulator will be capable of supplying the full volume required by both engines, but the use of two will provide reserve capacity. Subsequent low pressure regulators (as described in the next section) will reduce the pressure further for supply to the engines. It is estimated the the high and low pressure regulators will cost approximately $10 000 installed.

# Exhibit 12

## Engine Control System



## 5.6 Engine Conversion and Controls

The engine is assumed converted to pilot-fuel ignition, so that the vessel can operate on 100% diesel, if required, so as to provide operational flexibility and free choice of fuel. For such an engine, the major parts of the control system downstream of the low pressure regulator are:

- fuel ratio control mechanism and sensors
- diesel fuel volume control
- natural gas volume control
- natural gas injection mechanism

These are each described in the following paragraphs and ways of implementing them are illustrated in Exhibit 12. Their costs have been included in the estimates of engine conversion cost.

It is realized that marine operators have a preference for pneumatic controls over electric devices, where possible, to ensure safe reliable functioning. The specific methods of providing control in the final design should take this preference into account.

### Low Pressure Regulator

The low pressure regulator uses the engine's intake manifold pressure as a reference to determine the pressure gas it should supply. Since the engine is turbo-charged, this may range from approximately 25 kPa to 100 kPa (4 to 15 psig). The objective is to maintain the output gas pressure from this regulator at a minimum level, 20 to 25 kPa (3 to 4 psi) above the manifold pressure. This should be sufficient to ensure a prompt, positive response to opening the gas volume control.

### Fuel Ratio Control Mechanism and Sensors

Normally, diesel engines are controlled through a mechanical linkage that integrates the position of the engine speed control lever with the engine speed as sensed by a governor mechanism to feed more or less (as required) fuel to the cylinders on each injection stroke. Conversion to the partial use of natural gas requires that an additional mechanism be interposed to limit the travel of the diesel fuel volume control to the level required for satisfactory ignition, and then to open the natural gas volume control to provide the remainder of the engine's fuel requirements.

In order to avoid engine overheating, and possible damage, the fuel ratio control mechanism would also monitor electronically certain critical temperatures, such as cylinder head, diesel injector, and exhaust; diesel fuel pressure and flow, and gas pressures. Abnormal readings would trigger a return to normal full diesel operation, as well as indicators on the engine control panel.

Since the initial installation on each engine type will probably be the first of its kind, it is particularly important that comprehensive engine monitoring be maintained; initially this should be combined with continuous

recording of data. It is planned to start with a relatively small proportion of natural gas and gradually increase it, provided no adverse indications are detected. Thus a fail-safe controller and complete engine operating condition records are essential.

## Diesel Fuel Volume Control

Diesel fuel volume is normally controlled by a metering device controlling the quantity of fuel injected on each compression stroke. On the MAK, as on many large diesels, a separate device is provided for each cylinder, operated by common linkages running along each side of the engine. The amount of diesel delivered may be limited by limiting the travel of this linkage whenever natural gas is being used.

## Natural Gas Volume Control

The volume of natural gas supplied to the engine may be controlled with sufficient accuracy by a variable aperture type of valve placed in the low pressure supply line. This would be controlled by the fuel ratio control mechanism. It is anticipated that natural gas flow would be effectively continuous through this valve and it would not be necessary to time its opening and closing.

## Natural Gas Injection Mechanism

As noted above, the low pressure natural gas supply would be at a pressure slightly higher than manifold pressure, thus positively ensuring the delivery of the required amount of fuel. Gas would be injected directly into the intake manifold upstream of each set of intake valves, and would be mixed with the incoming intake air charge, to be ignited in the cylinder by the diesel pilot fuel.

## Manufacturer's Cooperation

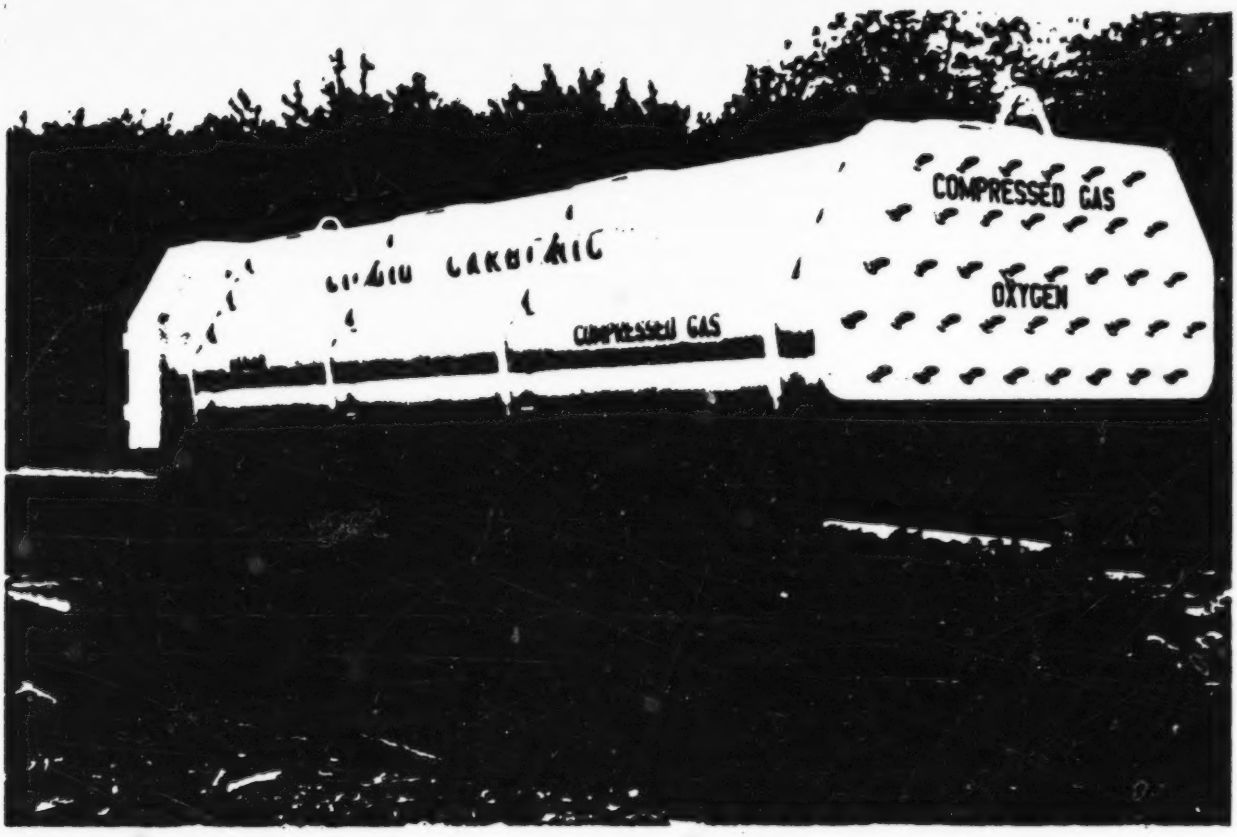
While the above represents a view of how engine conversion could be achieved and the fuel flow controlled, the final design should best be done by the manufacturer. All major B.C. Ferry vessels use M.A.K. engines and the problem has been discussed with M.A.K. representatives. They have responded positively and their Research Division is expected to make proposals.

## Monitoring

The design of the first installations should incorporate many sensors, recording devices, and adjustment points which would permit the experimentation necessary to achieve efficient operation on each engine type. Later installations will benefit from this work, and will be simpler and less costly.

EXHIBIT 10

Mobile Trailer




FIBA 55TC
38 TUBE CONVENTIONAL TRAILER

SIZE - 2 000 cu.m (70 000 SCF)

## 5.7 Safety System

A safety system is proposed to protect against:

- fire threatening the integrity of the high pressure cylinders
- any break at the trailer caused by collision or other means
- any break in the pipe between the shut-off valve on the trailer and the high pressure regulator
- any of the gas detectors recording a gas/air concentration above 20% of the lower flammable limit
- any failure in electric supply.

A schematic diagram of the safety system is shown in Exhibit 13. Each of the five major sub-systems is discussed below.

### Fire Threatening Integrity of the Cylinders

Burst disk units are mounted in the outlet piping of each of the high pressure storage cylinders on the trailer. If the pressure and temperature of the gas in any cylinder exceeds certain prescribed values - typically 26 000 kPa (3 775 psig) and 100°C (212°F) (indicating the presence of a fire), the burst disk will rupture and release the contents of the cylinder into the fuel compartment and from there to the outside atmosphere. The performance requirements for these burst disks are specified by Canadian Transport Commission regulations.

### Break at the Trailer Caused by Collision or Other Means

A mechanism will be mounted on the trailer at its outlet such that in the event of dislocation of the trailer producing a break, fuel flow will be halted.

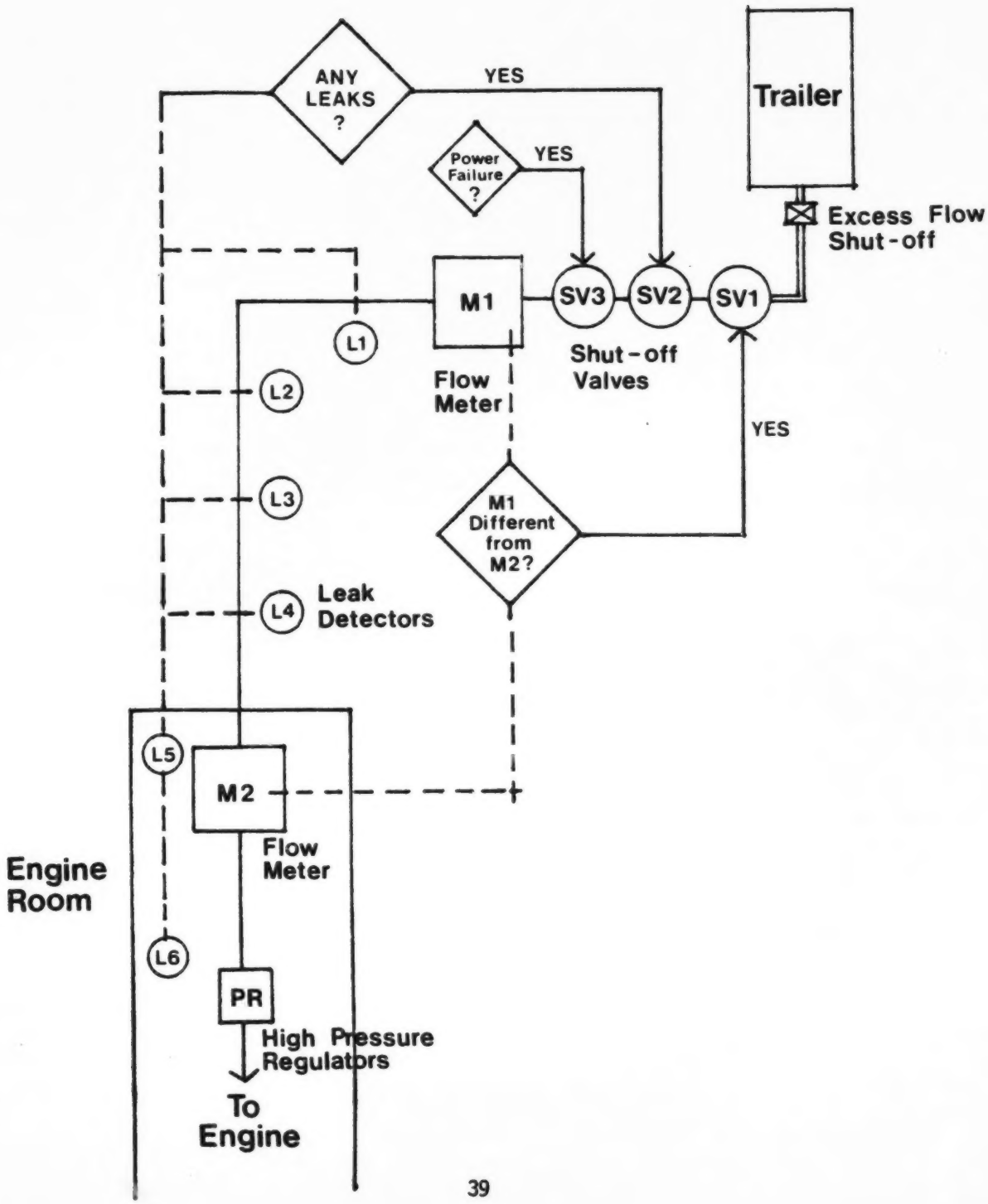
### Rupture of The Piping On The Vessel

Downstream of the trailer is a manifold (M1, in Exhibit 13) to which a natural gas flow meter is connected. A similar manifold (M2) and flow meter is also located in the engine room of the vessel. During operation of the ferry on natural gas, there is flow through each manifold and flow meter. The latter produces a series of voltage pulses whose frequency is proportional to the natural gas mass flow rate. The series of voltage pulses is converted to a DC voltage in a frequency to voltage converter. The corresponding output voltage from each flow meter is then applied to a differential amplifier.

In the event of a break in the natural gas line to the engine, there will be a large difference in the voltage output of the two flow meters. A control system uses a logic circuit such that if there is a large difference between the flow rates after allowing for the time delay to flow between the meters, the low voltage output from the differential amplifier will be used to close a solenoid actuated shut-off (SV1, in Exhibit 13). Hence in the event of a major break in the natural gas line to the engine, the flow from the high pressure storage cylinders will be shut off.

# Exhibit 13

## Safety System



### Leaks In The System

The above system is not sensitive enough to handle very small flow rate leaks from the system. To detect small leaks, a number of methane leak detectors are placed strategically along the natural gas line where natural gas pockets might collect. In the event of a leak which causes the gas/air mixture to reach 20% of the lower flammable limit, the output signal from the leak detector is used to close a shut-off valve. (SV2 in Exhibit 13). (The value of 20% of the lower flammable limit is used in the National Fire Protection Association Standard NFPA 52, for indoor refuelling stations supplying CNG to vehicles.)

### Power Failure

A power failure would immobilize the line-break and leak detector systems described above. A third solenoid-activated valve (SV3 in Exhibit 13) is therefore installed, such that the natural gas supply is shut off in the event of failure of the power supply. This valve and each of the other solenoid-activated valves above should be spring-loaded so that they close, at whatever angle to the vertical they may be inclined at the time there is a need for them to operate.

### Costs

The costs of the safety system as described above are estimated as $35 000, comprising about $20 000 for equipment and logic circuit design and $15 000 for installation and subsequent system test.

## 5.8 Costs

Tabulating the above costs leads to the following system estimate:

| | |
|---|---|
| Compressor units | $400 000 |
| Enclosures, controls etc. | 70 000 |
| Fuel compartment on vessel | 80 000 |
| Connections and piping | 25 000 |
| Pressure regulators | 10 000 |
| Safety system | 35 000 |
| | $620 000 |

| | |
|---|---|
| Trailers | $40 000 per year |
| Tractor (including fuel and maintenance) | $40 000 per year |

These costs have been included in Exhibit 6 earlier together with diesel conversion costs. The operating costs of Exhibit 7 show that these combined costs would be repaid by fuel savings in 2 to 3 years.

## 6.0 CONCLUSIONS

Based on the above analyses, the following conclusions may be drawn:

### Principal Ferries of Interest

- The principal ferries of interest on the East Coast are:

  . St. John to Digby
  . Prince Edward Island
  . North Sydney to Port-aux-Basques

  The other ferries either serve Newfoundland coastal communities where there is unlikely to be natural gas for many years or serve Argentia with long runs and low annual fuel consumption, such that the annual savings are unlikely to justify the high capital costs required.

- The principal ferries of interest on the West Coast are:

  . Langdale
  . Nanaimo
  . Victoria

  The Prince Rupert route is too long, requiring expensive on-board systems; the other runs are too short to justify the engine conversion costs, but could be candidates when new engines or vessels are considered.

### Prime Candidate - West Coast

The prime candidate appears to be the Langdale route where a simple system based on mobile refuelling using standard available equipment can repay its capital cost in 2 to 3 years. This application lends itself to subsequent expansion to the Nanaimo ferry system and the Victoria ferry system. These systems could be refuelled by mobile means (one 11.4 m - 37'6" long trailer would hold enough fuel for a round-trip on either the Nanaimo or Victoria route). Alternatively, an on-dock compressor and storage system to fill on-board fixed cylinders every round trip could be more economically attractive, since the costs of each on-dock system would be shared between more than one vessel, depending on how many vessels would be converted given the seasonality of the traffic.

### East Coast

On the East Coast, the prime candidate is the St. John to Digby route, which is served by a single vessel fuelled by diesel oil. Its conversion costs would be repaid by annual savings in 3 to 4 years. However, should the present vessel be replaced by a new one burning 90/10 blended fuel, then the economics would not be favourable based on fuel savings alone, since both fuels have approximately equal costs.

The Abegweit, Vacationland and Holiday Time have 6, 4 and 4 engines respectively to be converted, yet between them they consume not much more fuel in a year than the single Langdale ferry. If the costs of converting the first diesel engine of a given type to dual-fuel use are as high as conservatively estimated in this report and if the maintenance and reliability benefits of CNG over a blended fuel are ignored, then conversion of the Prince Edward Island Ferries would take 10 to 15 years of fuel saving to repay its costs. However, by the time consideration has to be given to converting the Prince Edward Island route, the conversion costs for large diesels may be better known and documented information on CN Marine maintenance experience with blended fuel may be available.

For the North Sydney to Port-aux-Basques route with a new vessel, there are no fuel savings in using CNG rather than a 90/10 blend of heavy fuel/diesel. The justification for selecting CNG for this application would have to lie in greater security of supply and lower maintenance or an estimate that natural gas prices will be lower (and/or heavy fuel prices higher) than assumed in this report.

## Long Term Potential

The potential within B.C. Ferries and CN Marine is to replace 45 to 65 million litres of liquid fuel a year with CNG (depending on the extent to which the Prince Edward Island and Port-aux-Basque routes turn out to be economical), i.e. to halve a fuel bill of approximately $15 to $20 million a year. There is a further potential for passenger ferries elsewhere in Canada, rail car and truck ferries and short-haul cargo vessels.

## Recommended Action

It is recommended that the next stage be the detailed design of a conversion of the Queen of Alberni serving the Langdale route, in which all physical, economic and safety factors are evaluated. An initiative has already been taken on this by the B.C. Ferry Corporation, which has contacted the engine manufacturers (M.A.K.), has established a committee including B.C. Hydro and the local Coastguard representatives and is preparing an implementation plan. If, after evaluation of all the factors, it is determined that the conversion should proceed, it is recommended that the Federal Government consider a program to cooperate with the B.C. Ferry Committee, monitor this first Canadian application, including measurement of engine and vessel performance costs before and after conversion, and to contribute to first-time costs which may represent a learning experience in this application, but which are justified by the future Canadian benefits.

# APPENDIX A

## Technical Data on the Ferry Vessels

# WEST COAST VESSELS

| VESSEL NAME | YEAR BUILT<br>YEAR CONVERSION<br>YARD | LENGTH OVERALL | BEAM | LOAD DRAFT | GROSS TONS | HORSE-POWER | PROPULSION | SPEED KNOTS | PASS. | CREW | AUTOS | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alberni | 1976 - VSY | 457' | 89' | 17'6" | 5279.08 | 12000 | 2 Diesel | 22.64 | 450 | 21 | 145 | |
| Bowen | 1965 - VMD<br>1979 - Length BYC | 278'9" | 64'2" | 12'6" | 1476.02 | 3600 | 4 Diesel | 14 | 390 | 6 | 70 | |
| Burnaby | 1965 - VMD<br>1969 - BDD<br>1973 - BDD | 426'5" | 78'7½" | 13'3" | 4902.59 | 6000 | 2 Diesel | 18 | 987 | 31 | 192 | |
| Coquitlam | 1976 - BDD | 457' | 89' | 17'6" | 6551.18 | 12000 | 2 Diesel | 22.22 | 1466 | 34 | 362 | |
| Cowichan | 1976 - Yarrows | 457' | 89' | 17'6" | 6551.18 | 12000 | 2 Diesel | 22.14 | 1466 | 34 | 362 | |
| Dogwood Princess II | 1979 - Canoe Cove | 42' | 12'5" | 3'6" | 20.57 | 400 | 2 Diesel | 16 | 38 | 2 | - | |
| Esquimalt | 1963 - VMD<br>1967 - BDD<br>1969 - BDD<br>1982 - BY | 426'5" | 78'7½" | 12'6 3/4" | 4890.68 | 6600<br>9000 | 4 Diesel<br>2 Diesel | 19 | 1360 | 34 | 376 | |
| Howe Sound | 1964 - Mar.Ind.<br>1971 - BDD<br>1976 - VSY | 241' | 60'6" | 10'9" | 795.01 | 1600 | 2 Diesel | 9.5 | 330 | 6 | 70 | |
| Islands | 1963 - BDD | 236' | 55' | 12' | 1717.26 | 3200 | 2 Diesel | 14 | 483 | 12 | 40 | |
| Mayne Queen | 1965 - VMD<br>1972 - Steel Bel.<br>1979 - Lengthn'g | 278'9" | 64'2" | 12'6" | 1475.68 | 3600 | 4 Diesel | 14 | 340 | 6 | 70 | |
| Mill Bay | 1956 - VMD | 120' | 32'6" | 6'3" | 174.89 | 152 | 1 Diesel | 8½ | 168 | 4 | 16 | |
| Nanaimo | 1964 - VMD<br>1969 - BDD<br>1974 - BDD | 426'5" | 78'7½" | 13'3" | 4938.75 | 6000 | 2 Diesel | 18 | 987 | 31 | 192 | |
| New Westminster | 1964 - VMD<br>1969 - BDD<br>1973 - BDD | 426'5" | 78'7½" | 13'3" | 4903.91 | 6000 | 2 Diesel | 18 | 987 | 31 | 192 | |

## WEST COAST VESSELS (Cont'd)

| VESSEL NAME | YEAR BUILT<br>YEAR CONVERSION<br>YARD | LENGTH OVERALL | BEAM | LOAD DRAFT | GROSS TONS | HORSE-POWER | PROPULSION | KNOTS | PASS. | CREW | AUTOS | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North | 1969 - Germany<br>1974 - BDD | 410'1 3/8" | 63'6" | 15'1 3/8" | 8806.76 | 15600 | 2 Diesel | 21 | 1040 | 60 | 157 | |
| Oak Bay | 1981 - BY | 457' | 89' | 17'6" | 6968.91 | 12000 | 2 Diesel | 22 | 1466 | 34 | 362 | |
| Powell River | 1965 - VHD<br>1973 - BDD<br>1979 - Lengthn'g | 278'9" | 64'2" | 12'6" | 1486.15 | 3600 | 4 Diesel | 14 | 400 | 6 | 70 | |
| Prince Rupert | 1966 - VHD<br>1973 - BDD | 331'10½" | 61'1 7/8" | 14'8" | 5864.07 | 8560 | 4 Diesel | 18 | 458 | 41 | 80 | |
| Seanich | 1963 - VHD<br>1968 - BDD<br>1972 - BDD<br>1982 - BY | 426'5" | 78'7½" | 13' | 4907.25 | 6600<br>9000 | 4 Diesel<br>2 Diesel | 19 | 1360 | 34 | 376 | |
| Salt Spring | 1949 - Yarrows<br>1969 | 145' | 36' | 6'0½" | 276.46 | 480 | 2 Diesel | 10 | 187 | 5 | 30 | |
| Sidney | 1960 - VHD<br>1971 - BDD | 336'4½" | 74' | 12'6" | 3127.86 | 6000 | 2 Diesel | 18 | 989 | 29 | 138 | |
| Surrey | 1981 - BY | 457' | 89' | 17'6" | 6968.91 | 12000 | 2 Diesel | 22 | 1466 | 34 | 362 | |
| Tsawwassen | 1960 - BDD<br>1969 - BDD | 336'4½" | 74'2 3/8" | 12'10" | 3127.33 | 6000 | 2 Diesel | 18 | 989 | 29 | 138 | |
| Vancouver | 1962 - BDD<br>1967 - BDD<br>1972 - VSY<br>1981 | 426'5" | 78'7½" | 13' | 4901.36 | 6600<br>9000 | 4 Diesel<br>2 Diesel | 19 | 1360 | 34 | 286 | |
| Vesuvius | 1950 - Yarrows<br>1962 - Allied | 150' | 36' | 6'0½" | 276.63 | 480 | 2 Diesel | 10 | 177 | 5 | 32 | |
| Victoria | 1962 - VHD<br>1968 - BDD<br>1970 - BDD<br>1981 - | 426'5" | 78'7½" | 12'7" | 4900.10 | 6600<br>9000 | 4 Diesel<br>2 Diesel | 19 | 1360 | 34 | 286 | |

# EAST COAST VESSELS

| | Year Built / Construit en | Port of Registry / Port d'attache | Length O/A / Longueur hors-tout | Beam / Largeur | Loaded Draft / Tirant d'eau en charge | Gross Tons / Jauge brute | Horsepower / Puissance | Propulsion | Speed (Kts.) / Vitesse (Nds) | Passengers / Passagers (max.) | Autos (max.) | Trucks / Camions (max.) | General Cargo / Cueillette | Rail Cars / Wagons |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M.V. Marine Runner | 1975 | St. John's | 91.4' | 22' | 5' | 138 | 1530 BHp* | 3 Diesel | 19 | 66 | No/Non | No/Non | No/Non | No/Non |
| M.V. Marine Sprinter | 1974 | St. John's | 94' | 22' | 5' | 128 | 1530 BHp | 3 Diesel | 19 | 60 | No/Non | No/Non | No/Non | No/Non |
| M.V. Marine Packer | 1965 | St. John's | 232' | 35' | 13' | 1101 | 1400 Hp | 1 Diesel | 10 | 12 | No/Non | No/Non | Yes/Oui | No/Non |
| M.V. Hopedale | 1960 | St. John's | 188' | 38' | 13' | 1105 | 3300 Hp | 2 Diesel | 12 | 98 | No/Non | 2 on deck sur le pont | Yes/Oui | No/Non |
| M.V. Taverner | 1962 | St. John's | 188' | 38' | 13' | 1135 | 3300 Hp | 2 Diesel | 12 | 102 | No/Non | 2 on deck sur le pont | Yes/Oui | No/Non |
| M.V. Petite Forte | 1961 | St. John's | 173' | 38' | 13' | 1048 | 2200 Hp | 2 Diesel | 12 | 102 | 2 on deck sur le pont | No/Non | Yes/Oui | No/Non |
| M.V. Bonavista | 1956 | St. John's | 215' | 35' | 15' | 1174 | 1280 BHp | 1 Diesel | 11 | 113 | 2 on deck sur le pont | No/Non | Yes/Oui | No/Non |
| M.V. Ambrose Shea | 1967 | St. John's | 391' | 71' | 21' | 9934 | 13000 SHp** | Diesel Elec. | 17 | 525 | 160 | 60 | No/Non | No/Non |
| M.V. Marine Cruiser | 1959 | London/Londres | 372' | 58' | 16' | 4141 | 8600 BHp | 2 Diesel | 16 | 389 | 78 | 32 | No/Non | No/Non |
| M.V. Marine Atlantica | 1975 | Nassau | 396' | 62' | 19' | 5441 | 14100 BHp | 2 Diesel | 18 | 1129 | 265 | 45 | No/Non | No/Non |
| M.V. Marine Nautica | 1974 | Nassau | 396' | 62' | 19' | 5443 | 14100 BHp | 2 Diesel | 18 | 1129 | 265 | 45 | No/Non | No/Non |
| M.V. Stena Nordica | 1976 | Goteborg | 394' | 62' | 19' | 5429 | 14100 BHp | 2 Diesel | 18 | 1100 | 265 | 45 | No/Non | No/Non |
| M.V. Frederick Carter | 1967 | St. John's | 486' | 71' | 20' | 12220 | 16900 BHp | 4 Diesel | 18 | 12 | No/Non | 40 | No/Non | Yes/Oui |
| M.V. Sir Robert Bond | 1975 | Ottawa | 444' | 70' | 18' | 10433 | 10560 BHp | 4 Diesel | 15 | 260 | 120 | 25 | Yes/Oui | Yes/Oui |
| M.V. Abegweit | 1947 | Charlottetown | 373' | 63' | 19' | 6694 | 12000 BHp | Diesel Elec. | 12 | 400 | 109 | No/Non | No/Non | Yes/Oui |
| M.V. John Hamilton Gray | 1968 | Charlottetown | 400' | 67' | 20' | 11259 | 16000 BHp | Diesel Elec. | 17 | 550 | 190 | 19 | No/Non | Yes/Oui |
| M.V. Holiday Island | 1971 | Charlottetown | 325' | 68' | 17' | 3037 | 7250 BHp | 2 Diesel | 15 | 487 | 80 | 20 | No/Non | No/Non |
| M.V. Vacationland | 1971 | Charlottetown | 325' | 68' | 17' | 3037 | 7250 BHp | 2 Diesel | 15 | 487 | 80 | 20 | No/Non | No/Non |
| M.V. Princess of Acadia | 1971 | Saint John/ St-Jean | 480' | 66' | 15' | 10051 | 11480 BHp | 4 Diesel | 20 | 650 | 159 | 40 | No/Non | No/Non |
| M.V. Marine Evangeline | 1978 | Nassau | 361' | 58' | 15' | 2793 | 10200 BHp | 4 Diesel | 18 | 120 | 240 | 55 | No/Non | No/Non |
| M.V. Bluenose | 1955 | Yarmouth | 346' | 65' | 17' | 6419 | 12000 BHp | 6 Diesel | 16 | 615 | 165 | 18 | No/Non | No/Non |

## APPENDIX B

## Fuel Energy Equivalents

1. Canadian Government Specifications for #2 Diesel

CAN. 2 23.6 - M81

| | | |
|---|---|---|
| 19620 BTU/lb | = 45.5 | MJ/Kg |
| 165946 BTU/Imperial gallon | = 38.5 | MJ/litre |
| 8.458 lb/Imperial gallon | = 0.846 | Kg/litre |

2. Statistics Canada

| | | |
|---|---|---|
| Diesel | = 38.68 | MJ/litre |
| Gasoline | = 34.66 | MJ/litre |
| Natural Gas | = 37.23 | MJ/cu.m |
| Heavy Fuel | = 41.73 | MJ/cu.m |

3. Chevron Canada, Vancouver, B.C.

| | | |
|---|---|---|
| #2 Diesel:165000 BTU/Imperial gallon | = 38.3 | MJ/litre |

4. Bosch Automotive Handbook

| | | |
|---|---|---|
| Diesel 40.6 to 44.4 MJ/kg | = 34.3-37.6 | MJ/litre |
| Gasoline 44.9 MJ/kg @ 0.72 kg/litre | = 32.3 | MJ/litre |
| Natural Gas 50.1 MJ/kg @ .7174 kg/cu.m | = 35.94 | MJ/cu.m |

5. B.C. Hydro

| | | |
|---|---|---|
| Natural Gas 1050 BTU/SCF | = 39.09 | MJ/cu.m |

6. Handbook of Aplied Engineering Science

| | | |
|---|---|---|
| #2 Diesel 19110 BTU/lb [@ .846 kg/litre] | = 44.3 | MJ/kg |
| @ .846 kg/litre | = 37.5 | MJ/litre |

7. B.C. Ministry of Energy Forecaster

| | | |
|---|---|---|
| #2 Diesel | = 38.67 | MJ/litre |

## Assumptions for Report Based on the Foregoing

#2 Diesel contains: 38.5 MJ/litre
Natural Gas contains: 39.1 MJ/cu.m

i.e. 0.985 cu.m (or 34.77 SCF) or natural gas is equivalent to 1.0 litres of #2 diesel.

| West Coast Assume: | per gigajoule (GJ) |
|---|---|
| Diesel is 31¢/litre | = $8.04 |
| Natural gas - firm | = $4.04 |
| - interruptible | = $3.32 |
| Interruptible natural gas/diesel @ 80/20 mix | = $4.26 |
| **East Coast Assume:** | |
| Diesel is 31¢/litre | = $8.04 |
| Natural gas - firm | = $4.74 |
| - interruptible | = $3.80 |
| Interruptible natural gas/diesel @ 80/20 mix | = $4.64 |
| Blended fuel (40% heavy/60% diesel) 27¢/litre | = $7.01 |
| Heavy fuel mix (90% heavy/10% diesel) 23¢/litre | = $5.51 |